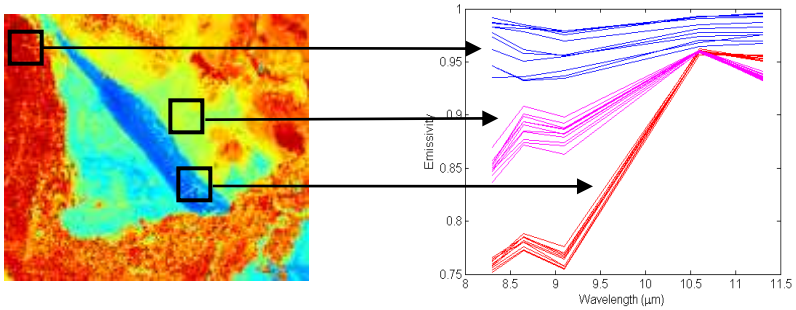
Jet Propulsion Laboratory
California Institute of Technology

An Intercomparison of AIRS, MODIS, and ASTER Land Surface Temperature and Emissivity (LST&E) Measurements



Simon Hook[a]

Glynn Hulley[a], Bob Knuteson[b]

[a] Jet Propulsion Laboratory, Caltech, Pasadena, CA

[b] University of Wisconsin-Madison

MODIS, AIRS, ASTER LST&E Climate Product Characteristics

Potential Sources of Bias

	Terra/Aqua **MODIS**	Aqua **AIRS**	Terra **ASTER**
Cloud Contamination	Cloud Detection	Cloud Clearing	Cloud Detection
Algorithm	Day/Night Land Cover Class	Multi-spectral	Calibration Curve
Temporal Sampling	Clear only; 10:30 AM, PM 1:30 AM, PM Twice daily	Partly Cloudy; 1:30 AM, PM Twice daily	Clear only 10:30 AM, PM every 16 days
Spatial Sampling and Resolution	1 km Clear Only (1 km –> 5 km)	45 km CC (15 km –> 45 km)	90 m Clear only
Scan angle	55	45	8.55

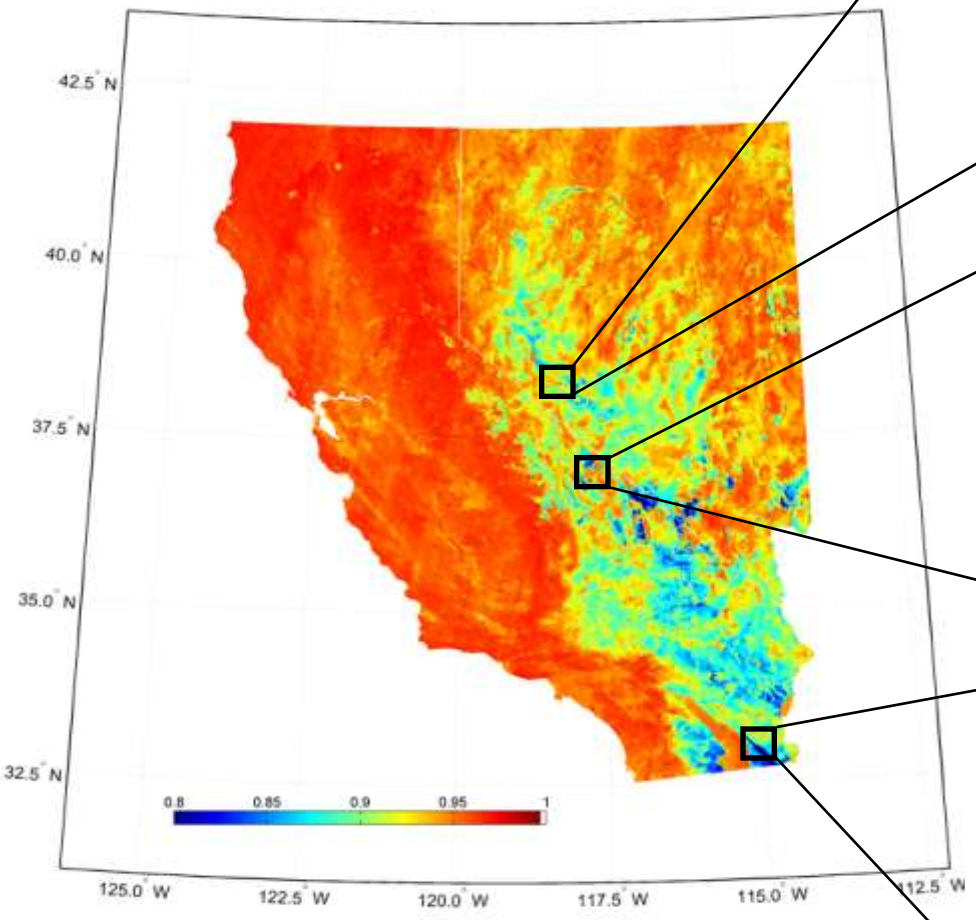
ASTER Gridded L3 Emissivity Product

- Mean Summer (July, Aug, Sep) and Winter (Jan, Feb, Mar) emissivity from 2000-2008
- ASTER Land Surface Emissivity Aggregation Algorithm (ALSEA)
- Use New ASTER Cloud Mask (NACMA) to screen out cloudy pixels (MODIS/AVHHR/Landsat)
- Determine all intersecting granules on 1 x1 given grid
- Output mean and temporal SDev for all clear obs on each pixel
- 100 m spatial resolution
- States completed:
  - California, Nevada, Arizona, Utah, New Mexico, Oklahoma, Texas
- Complete USA by end of year??

**** Hulley, G.**, S. J. Hook, 2008, The ASTER Land Surface Emissivity Database of California and Nevada, *Geophys. Res. Lett.*, in review.

ASTER Validation Sites

- Rocks and Sand



Cuprite, NV (03/26/08)

Carbonate

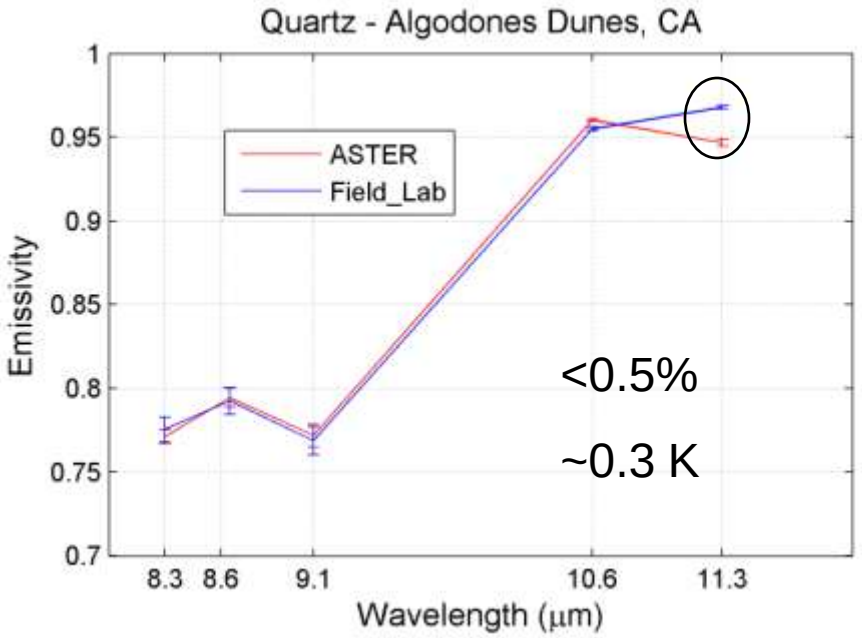
Stovepipe Wells Dunes (03/27/08)

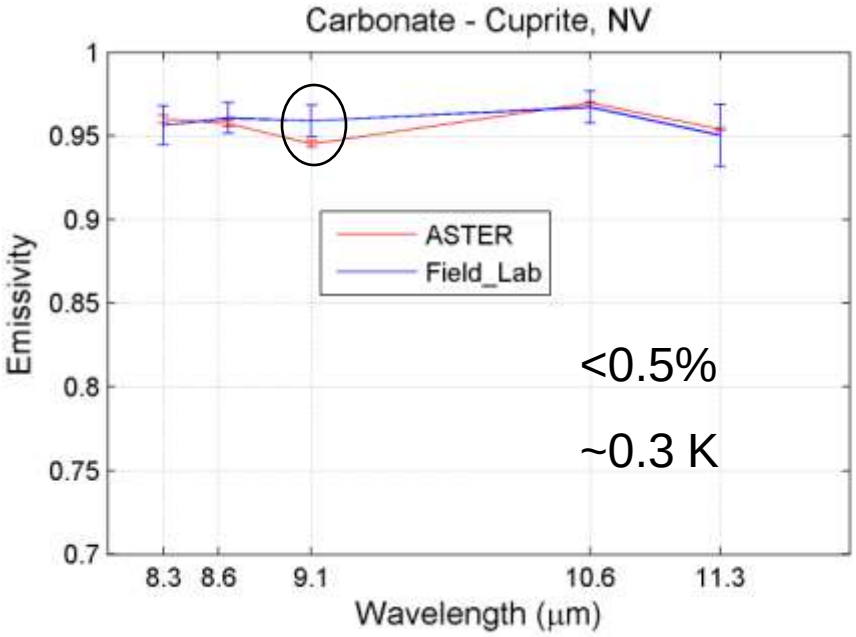
Algodones Dunes (03/24/08)

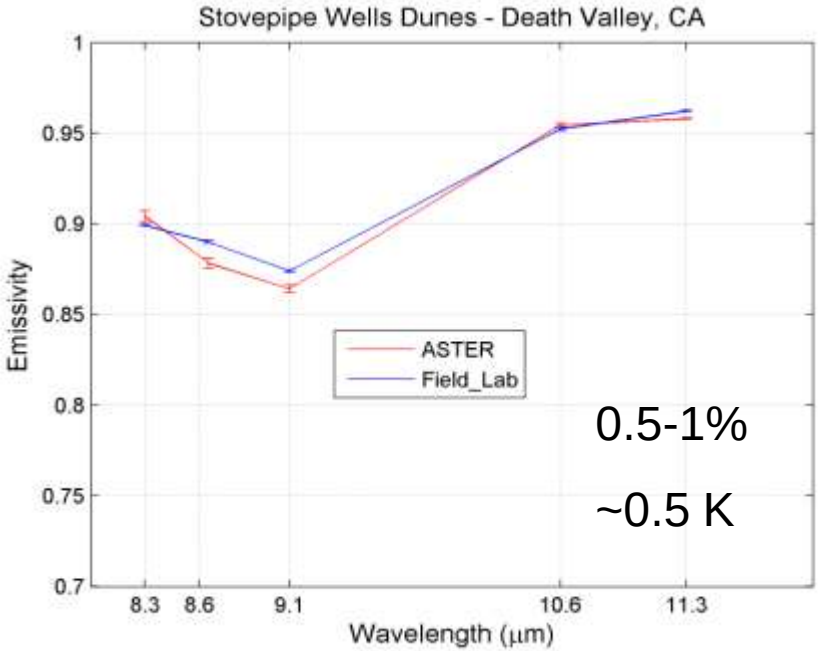
Quartz

10 samples at each site over 500m² area

2x2 ASTER pixels (100 m) averaged over each sample

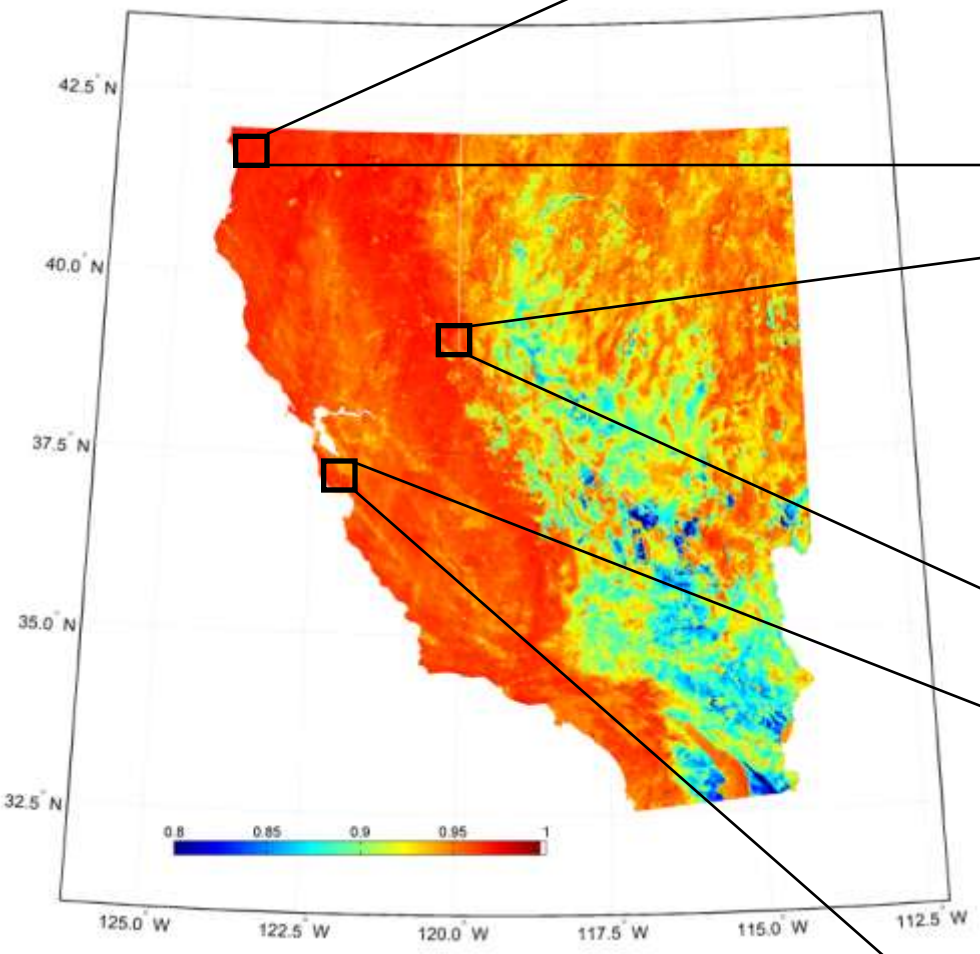

Quartz - Algodones Dunes, CA
ASTER
Field_Lab
<0.5%
~0.3 K
Emissivity
Wavelength (μm)
1
0.95
0.9
0.85
0.8
0.75
0.7
8.3
8.6
9.1
10.6
11.3


Carbonate - Cuprite, NV
ASTER
Field_Lab
<0.5%
~0.3 K
Emissivity
Wavelength (μm)
1
0.95
0.9
0.85
0.8
0.75
0.7
8.3
8.6
9.1
10.6
11.3


Stovepipe Wells Dunes - Death Valley, CA
ASTER
Field_Lab
0.5-1%
~0.5 K
Emissivity
Wavelength (μm)
1
0.95
0.9
0.85
0.8
0.75
0.7
8.3
8.6
9.1
10.6
11.3

ASTER Validation Sites

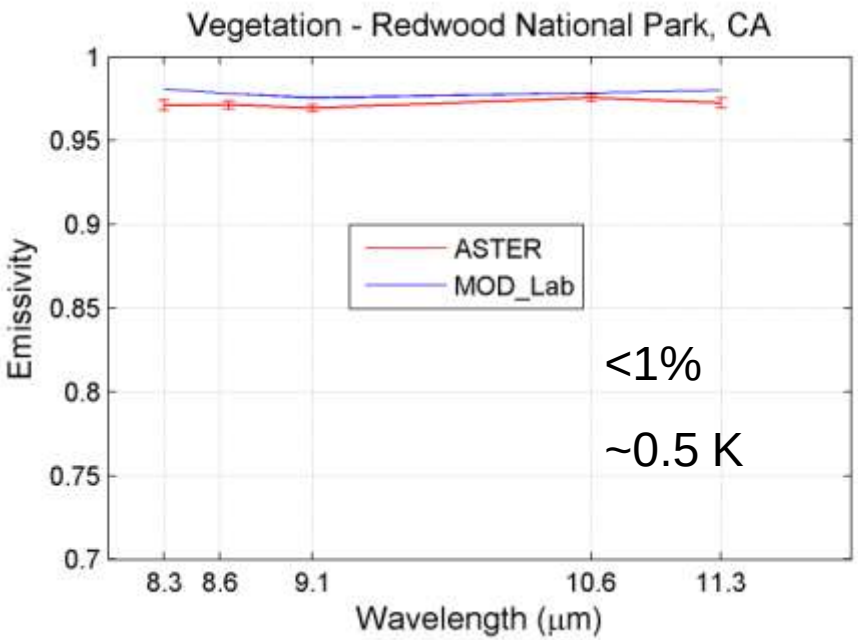
- Vegetation and Water

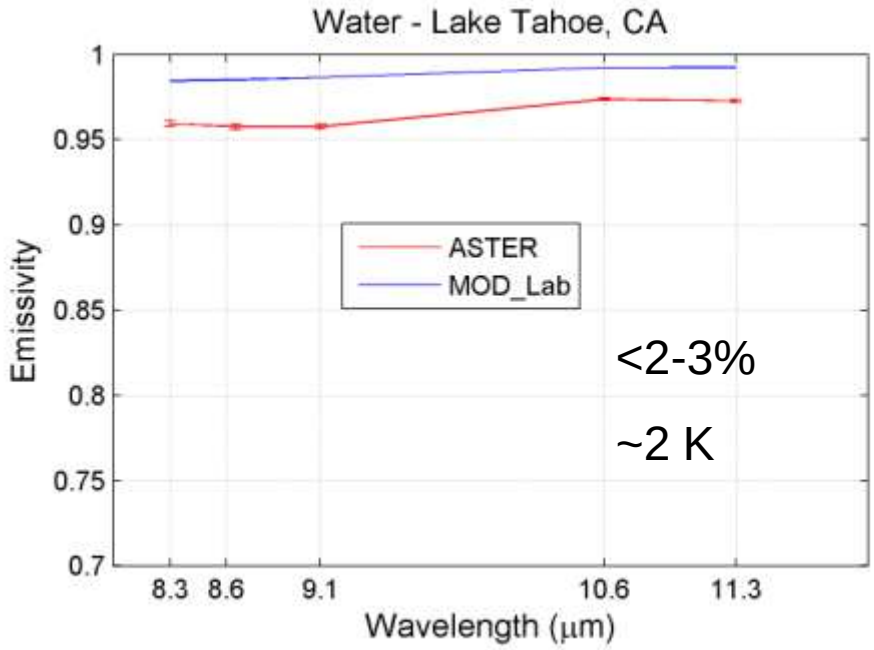


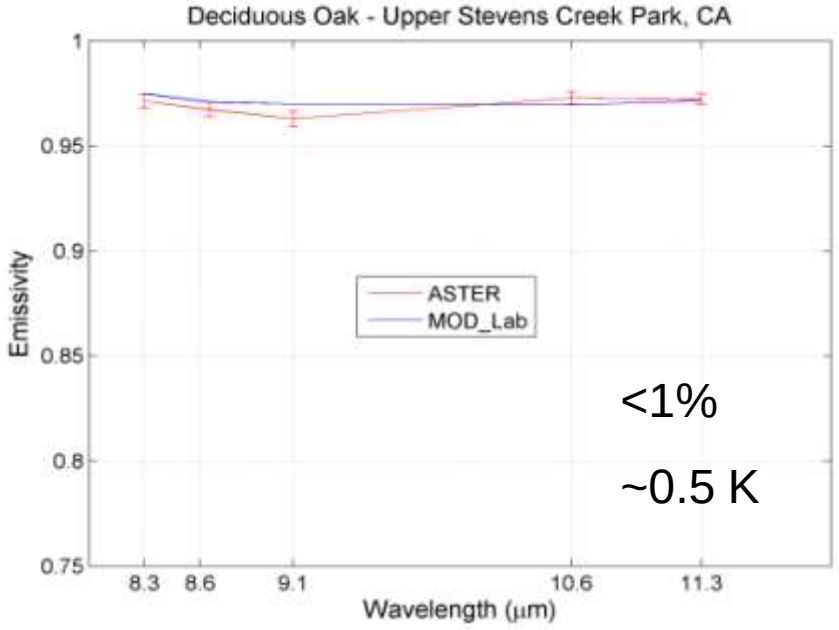
Redwood National Park – Conifer Forest

Lake Tahoe - Water

Stevens Creek Oak Forest - Deciduous

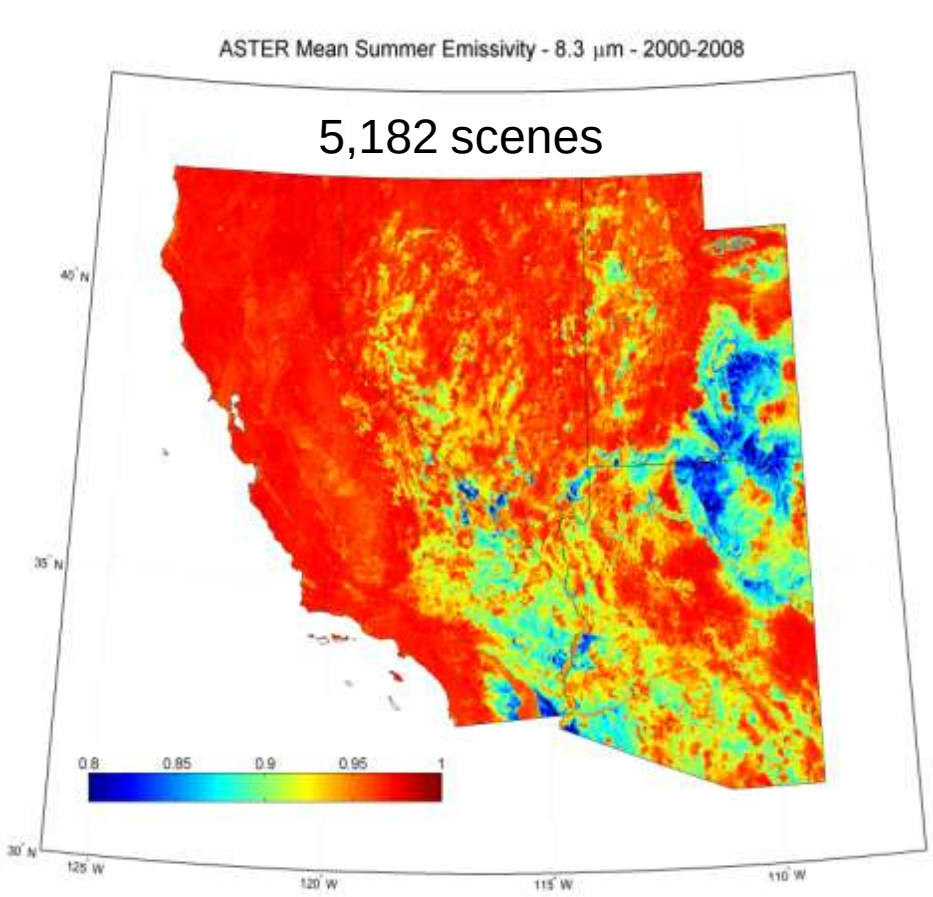


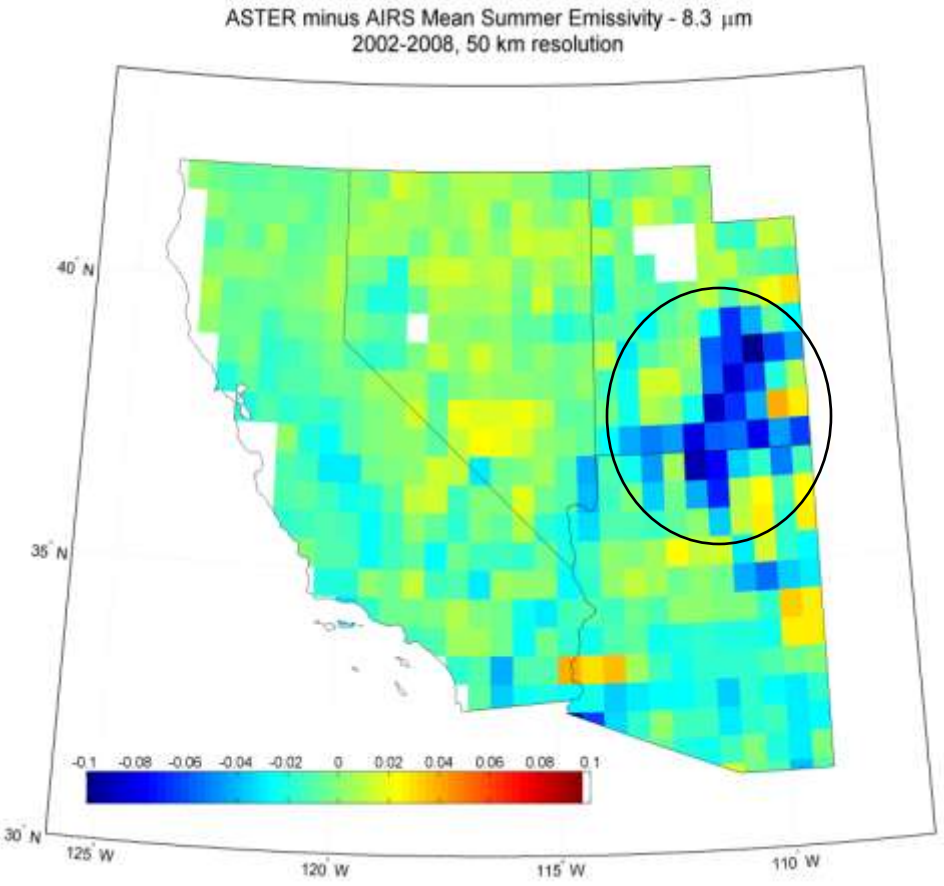




MODIS UCSB spectral library

ASTER minus AIRS (v5) Mean Summer Emissivity Differences



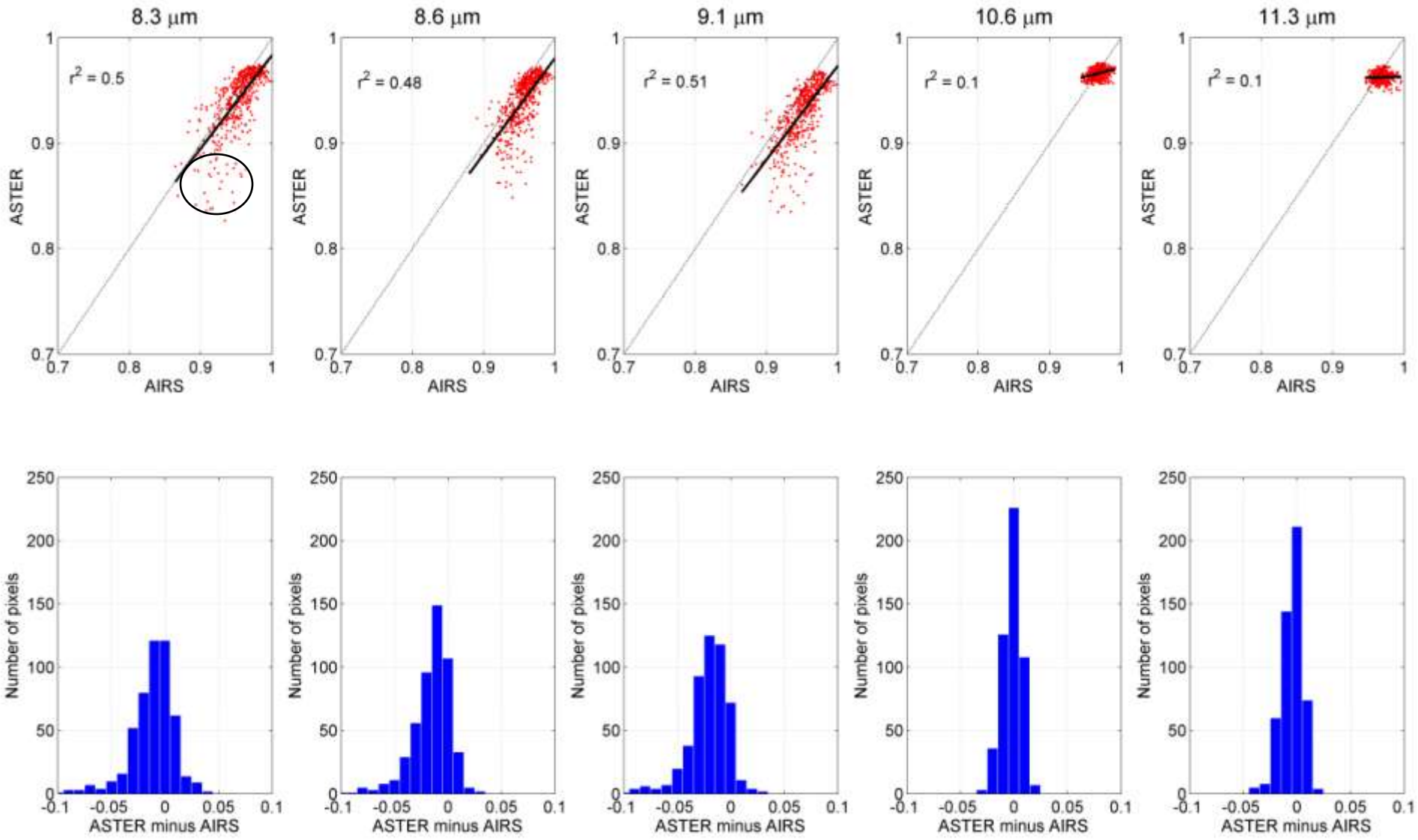


** 80% of pixels have less than 1.5% emissivity difference (~1 K)

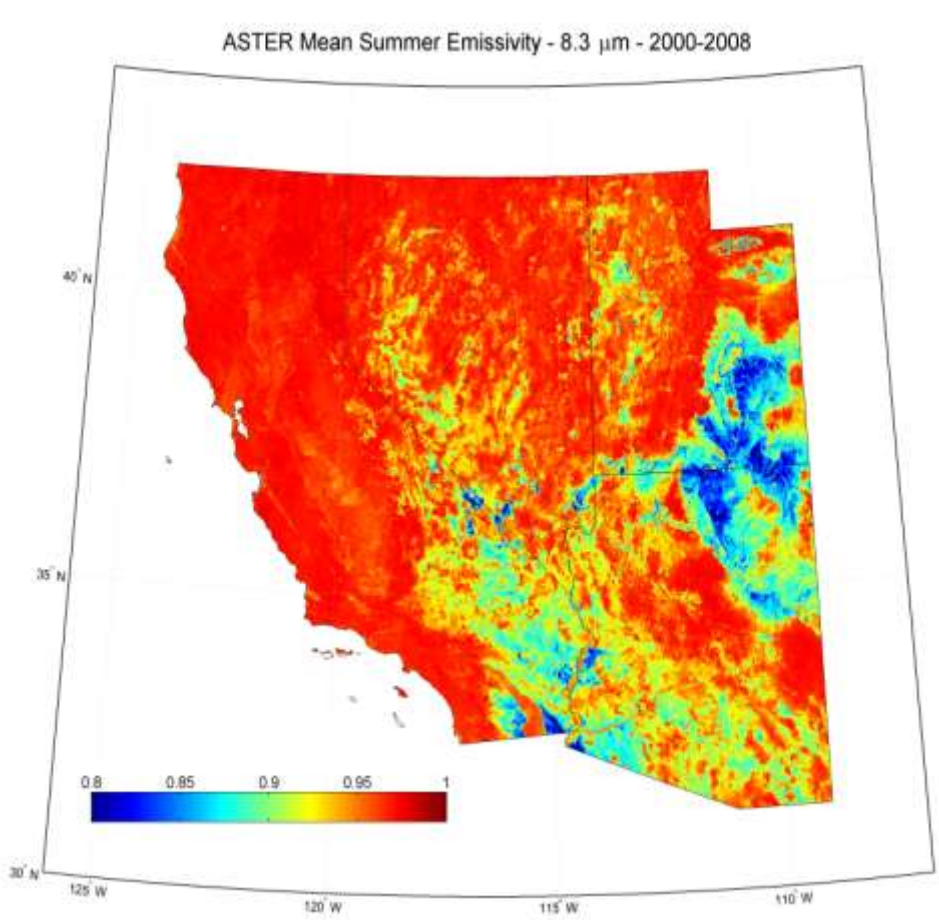
** Low emissivity areas have differences up to 7% (6.5 K)

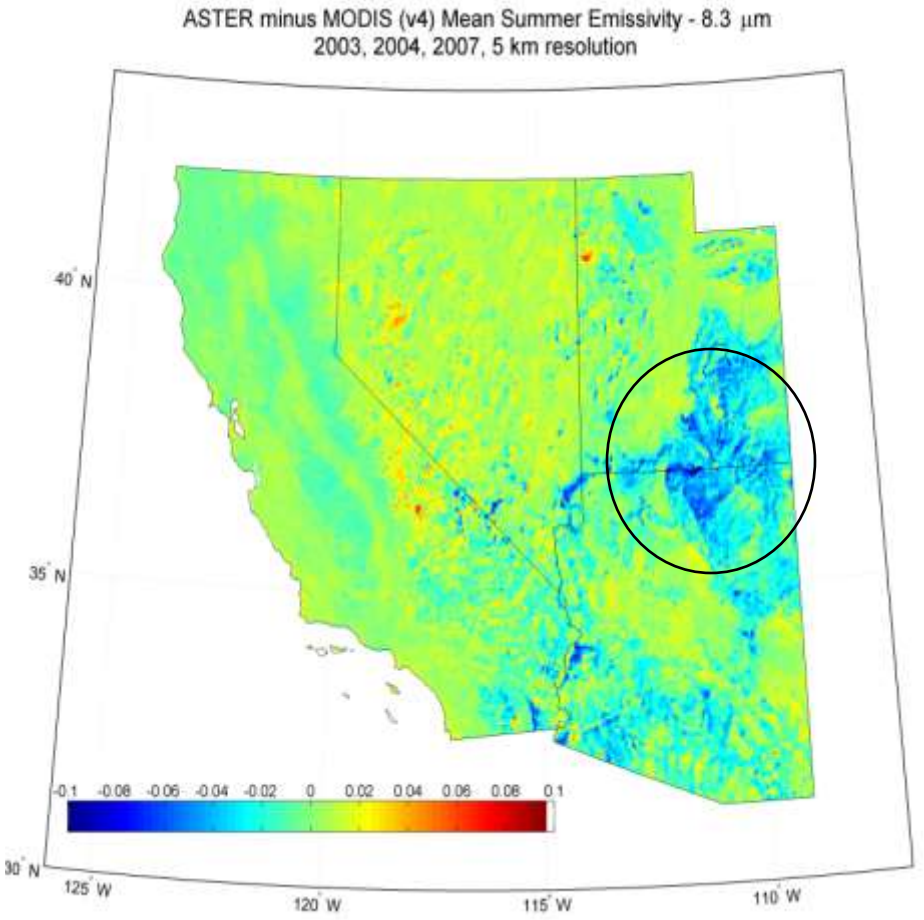
But could be due to AIRS overestimating nighttime emissivities over barren areas

ASTER and AIRS Emissivity Comparisons for all 5 TIR bands



ASTER minus MODIS (MYD11C3 V4) Mean Summer Emissivity Difference

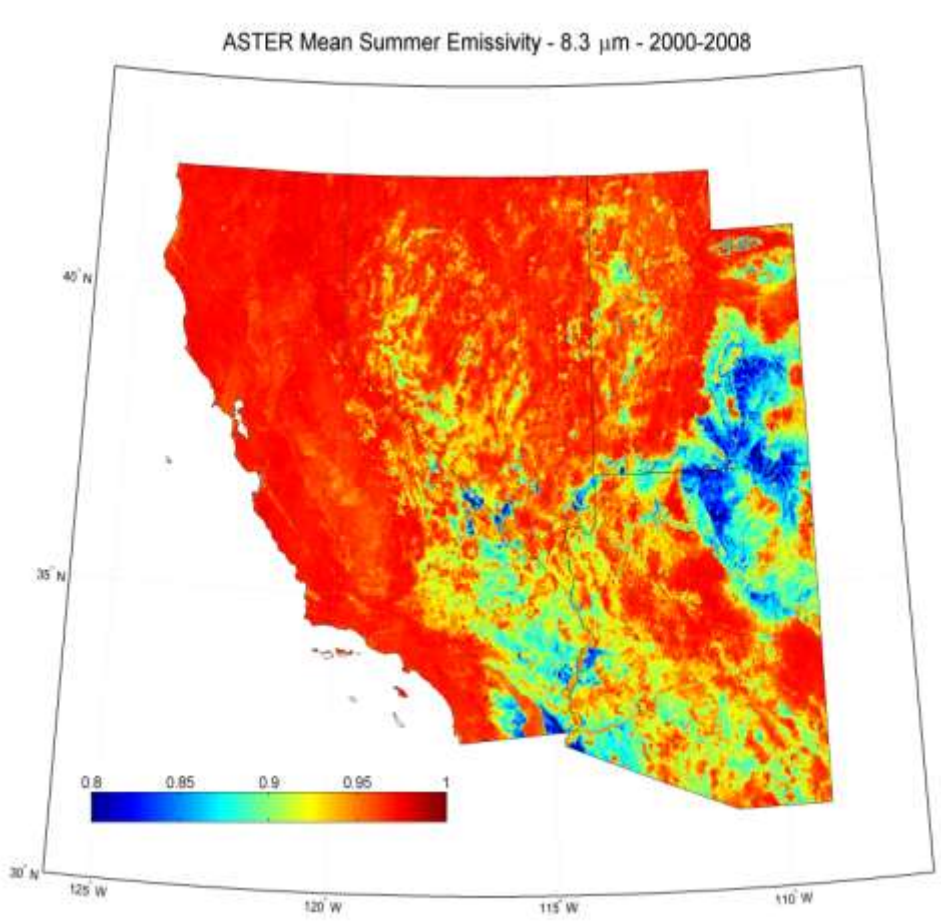


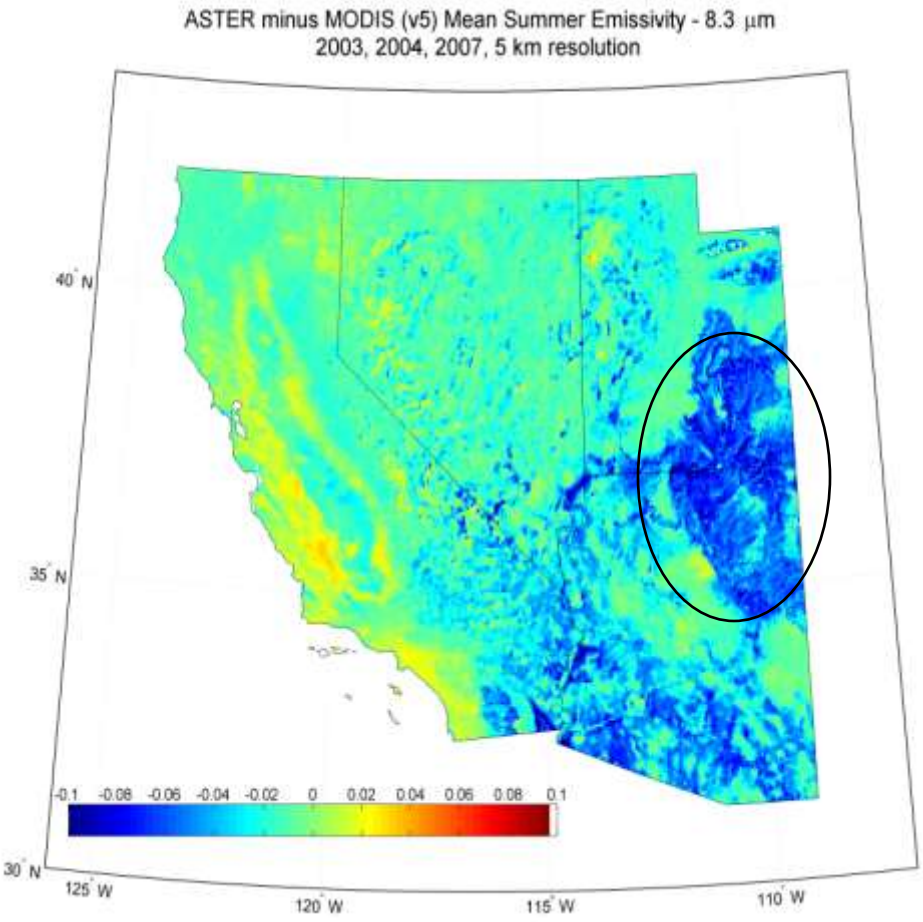


** 80% of pixels have less than 1% emissivity difference (~0.8 K)

** Low emissivity areas have differences up to 6% (~4.5 K)

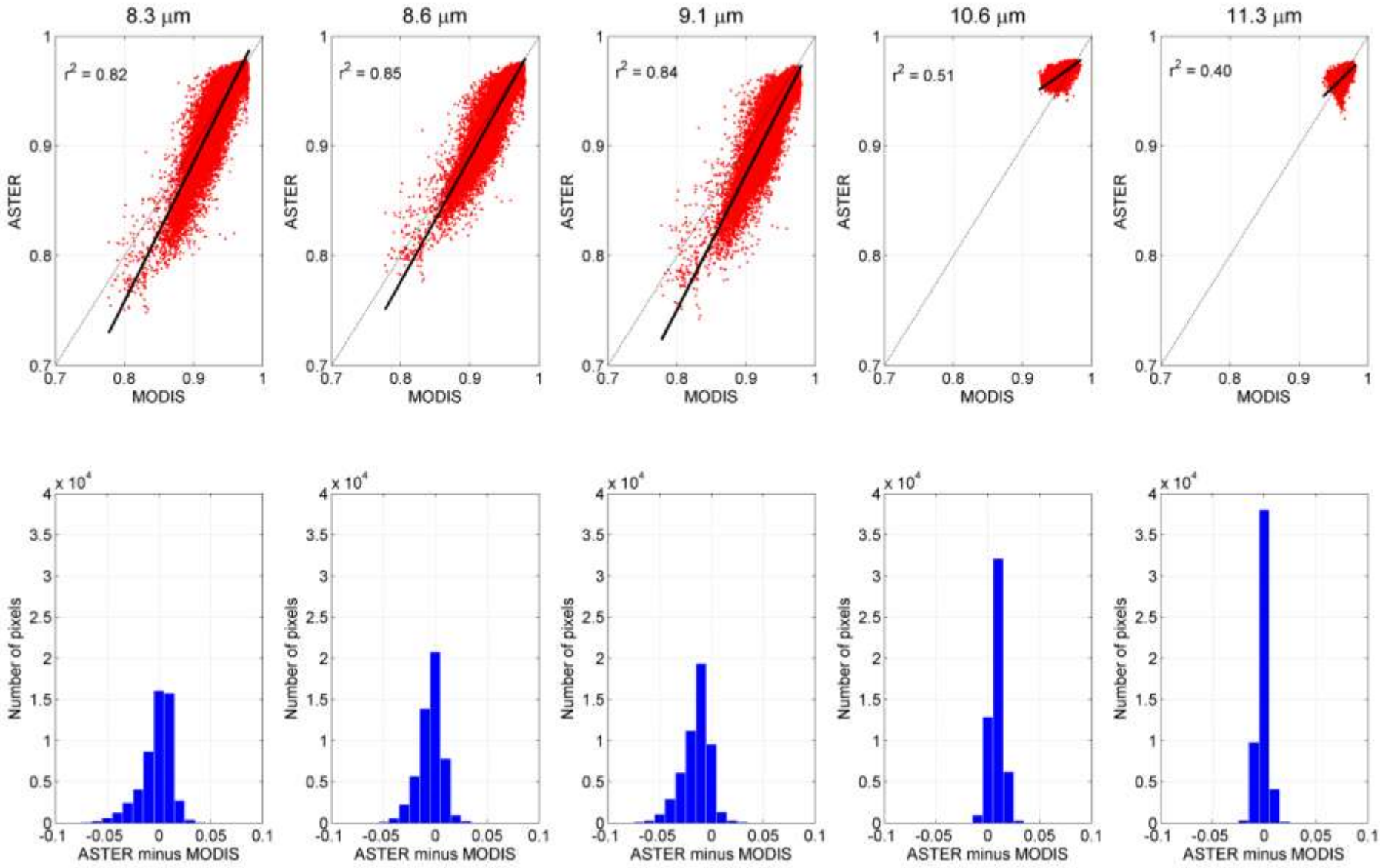
ASTER minus MODIS (MYD11C3 V5) Mean Summer Emissivity Difference



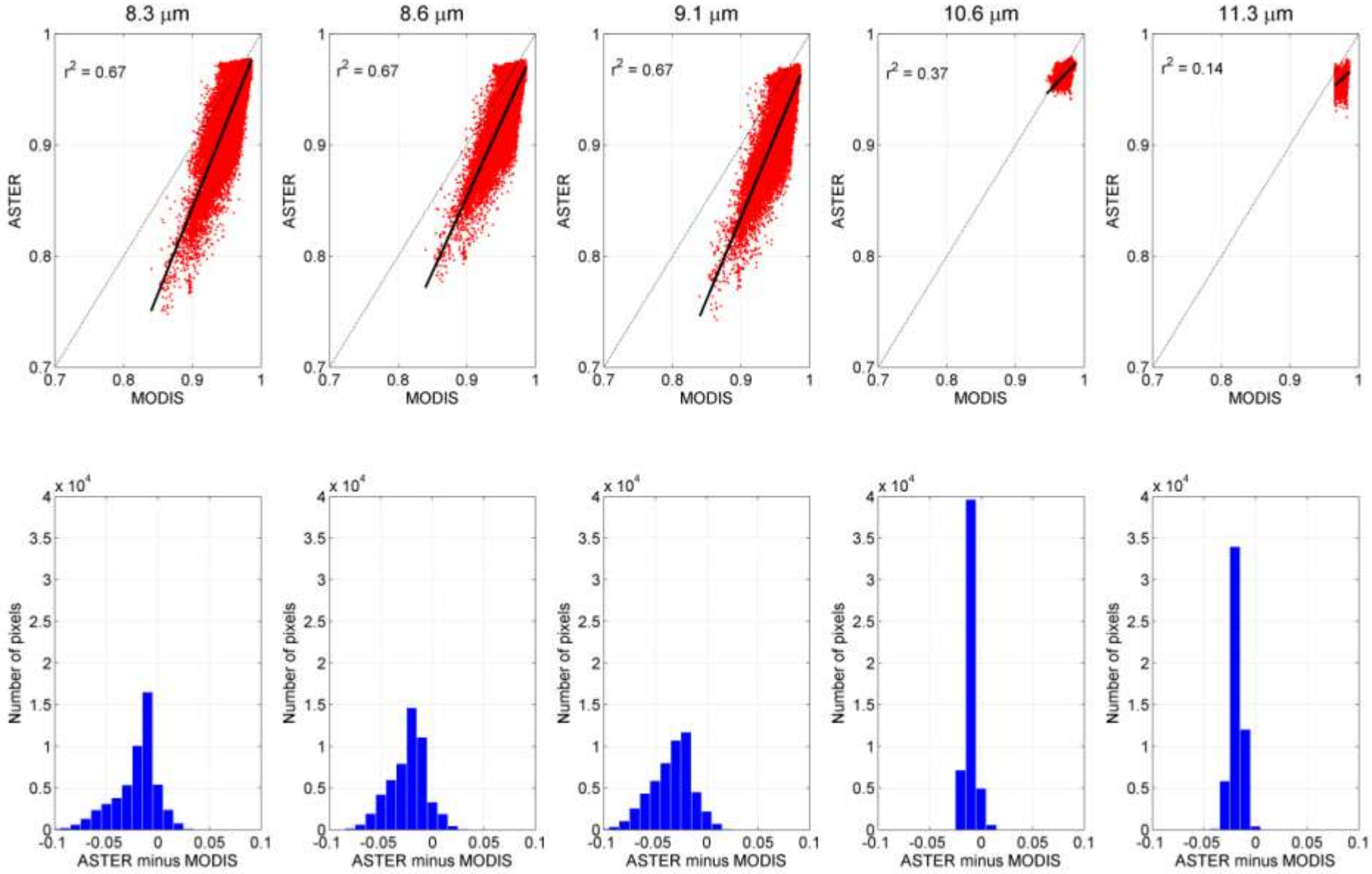


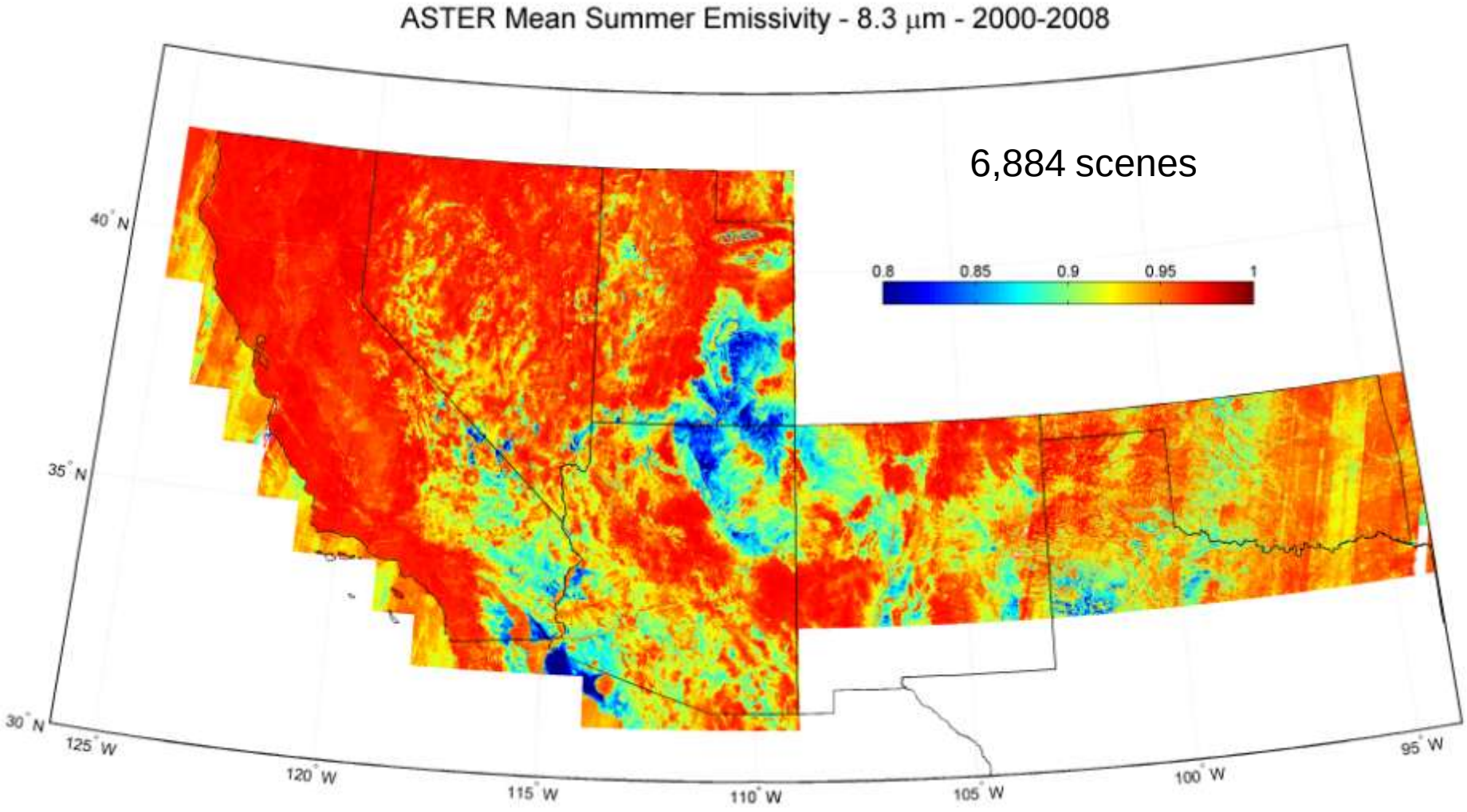
- MODIS (v5) uses Day/Night combined with Split-Window Land Cover type
- **Up to 10% emissivity difference in arid/semi-arid areas!! (~7 K)**

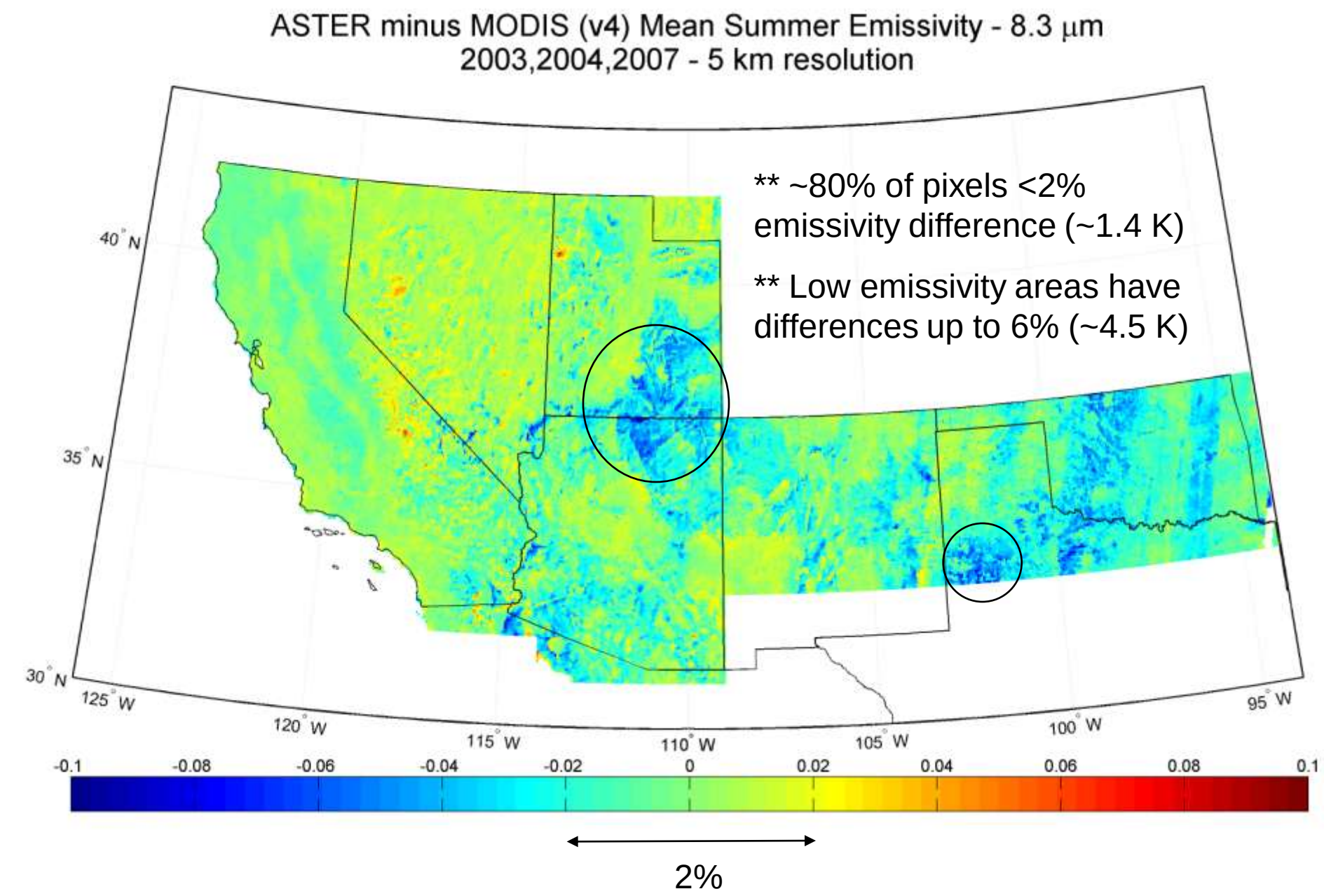
ASTER and MODIS (v4) Emissivity Comparisons for all 5 TIR bands

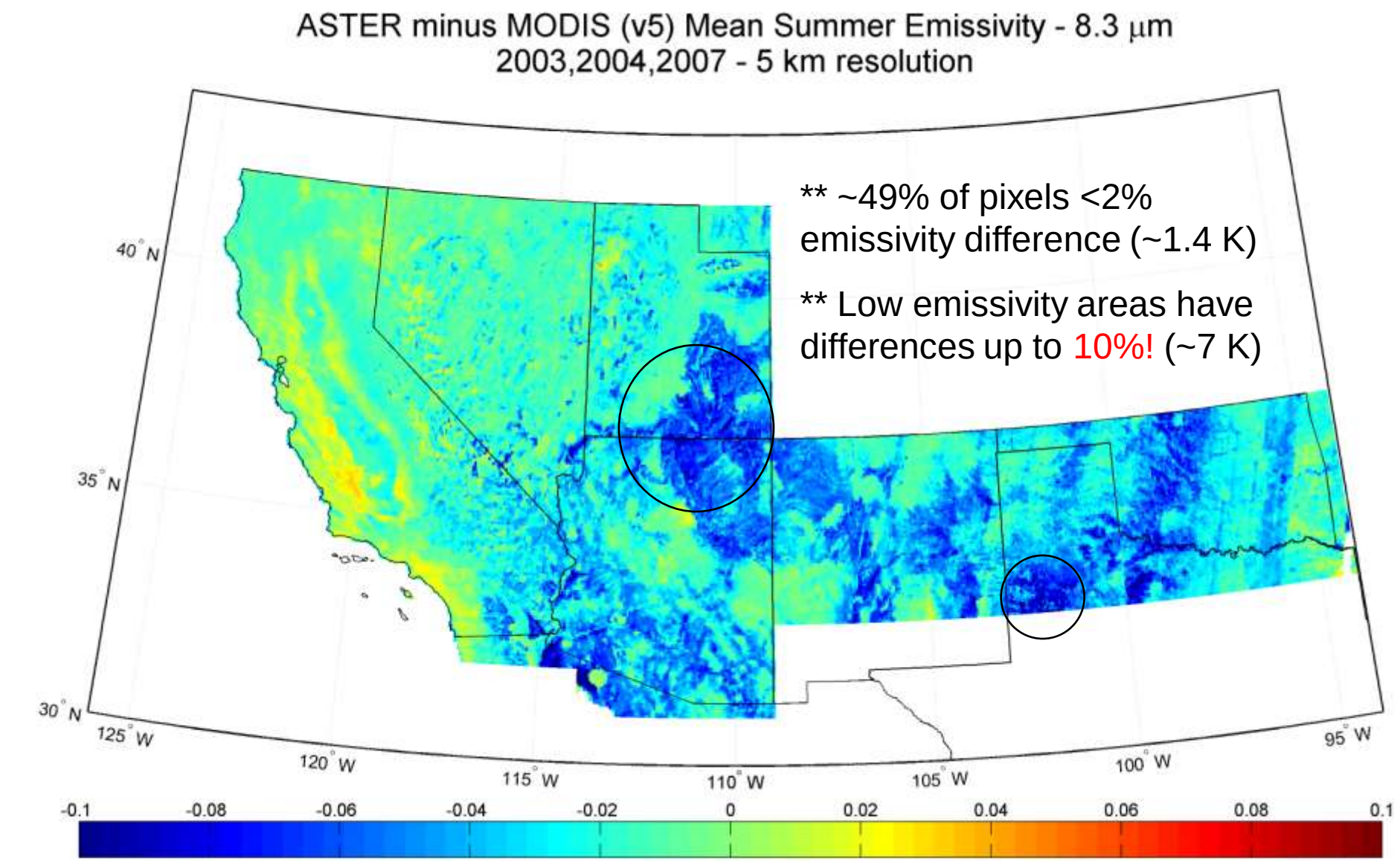


ASTER and MODIS (v5) Emissivity Comparisons for all 5 TIR bands

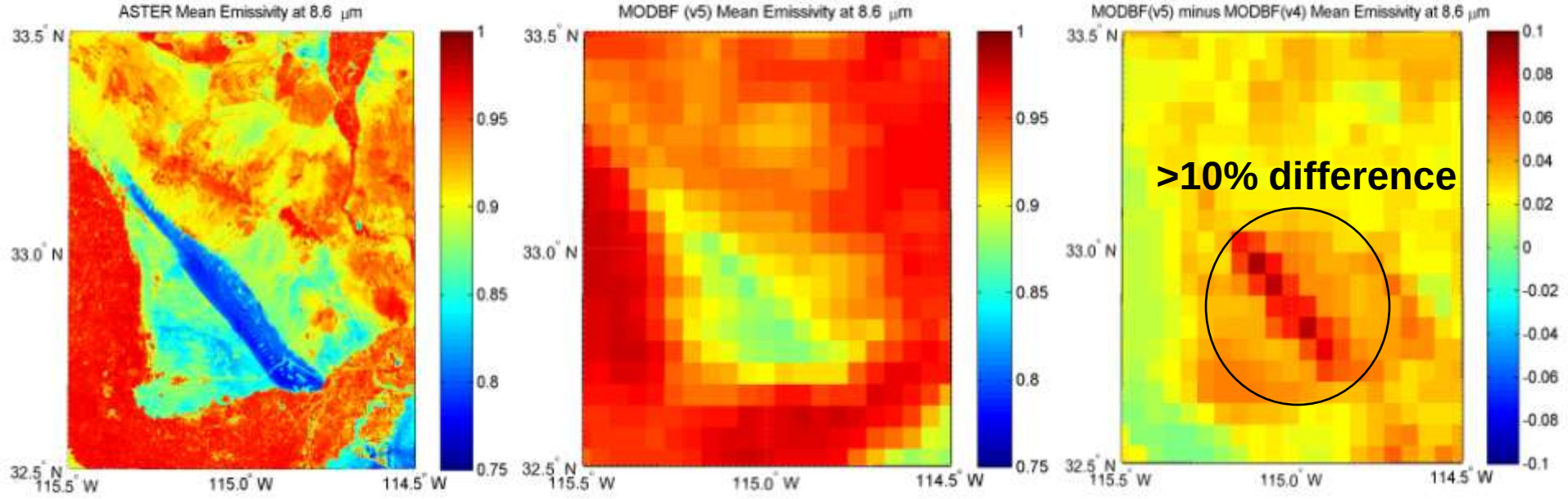



ASTER Mean Summer Emissivity - 8.3 μm - 2000-2008
6,884 scenes
0.8
0.85
0.9
0.95
1
40° N
35° N
30° N
125° W
120° W
115° W
110° W
105° W
100° W
95° W

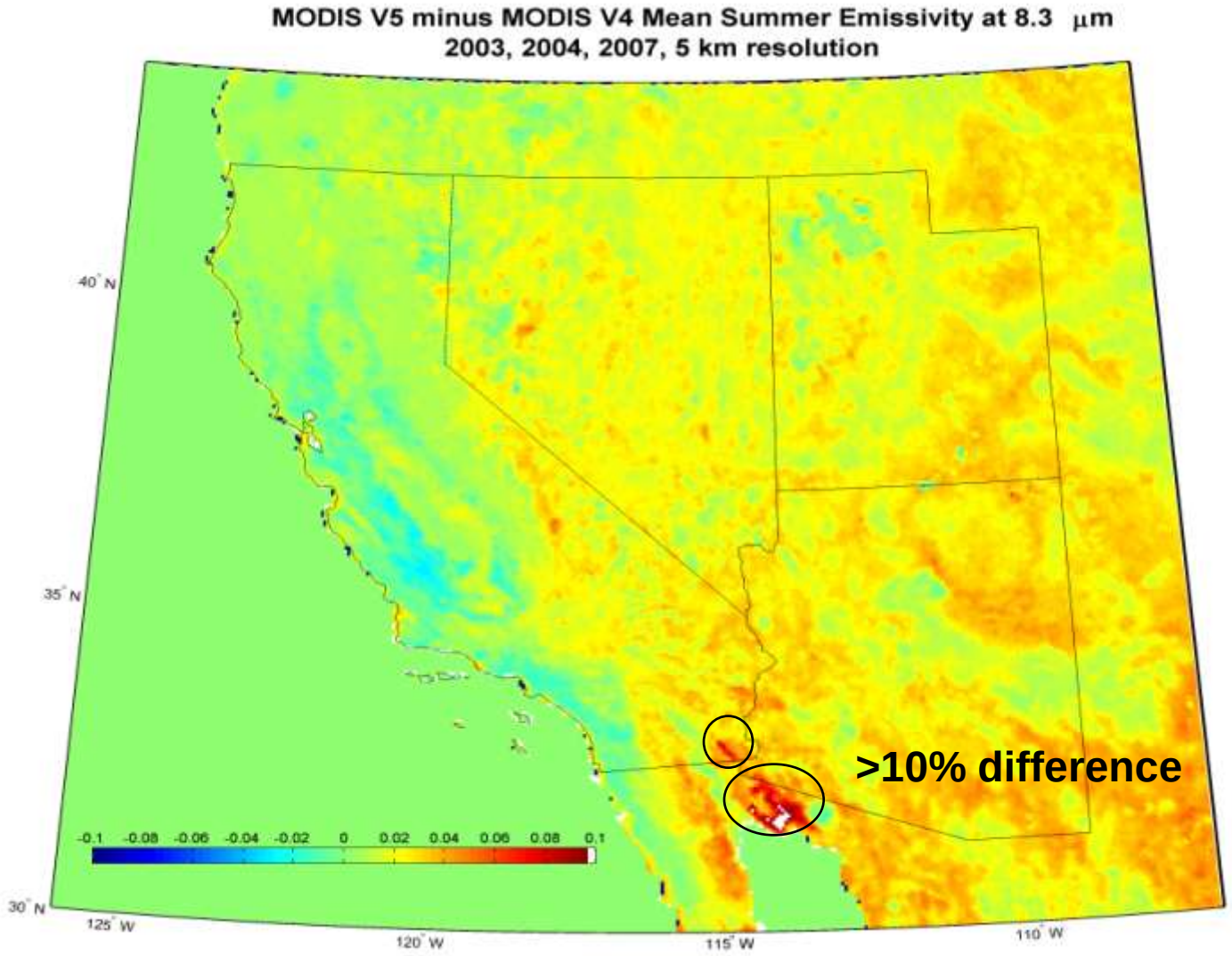

ASTER minus MODIS (v4) Mean Summer Emissivity - 8.3 μm
2003,2004,2007 - 5 km resolution
** ~80% of pixels <2% emissivity difference (~1.4 K)
** Low emissivity areas have differences up to 6% (~4.5 K)
40° N
35° N
30° N
125° W
120° W
115° W
110° W
105° W
100° W
95° W
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
2%


ASTER minus MODIS (v5) Mean Summer Emissivity - 8.3 μm
2003,2004,2007 - 5 km resolution
** ~49% of pixels <2% emissivity difference (~1.4 K)
** Low emissivity areas have differences up to 10%! (~7 K)
40° N
35° N
30° N
125° W
120° W
115° W
110° W
105° W
100° W
95° W
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1

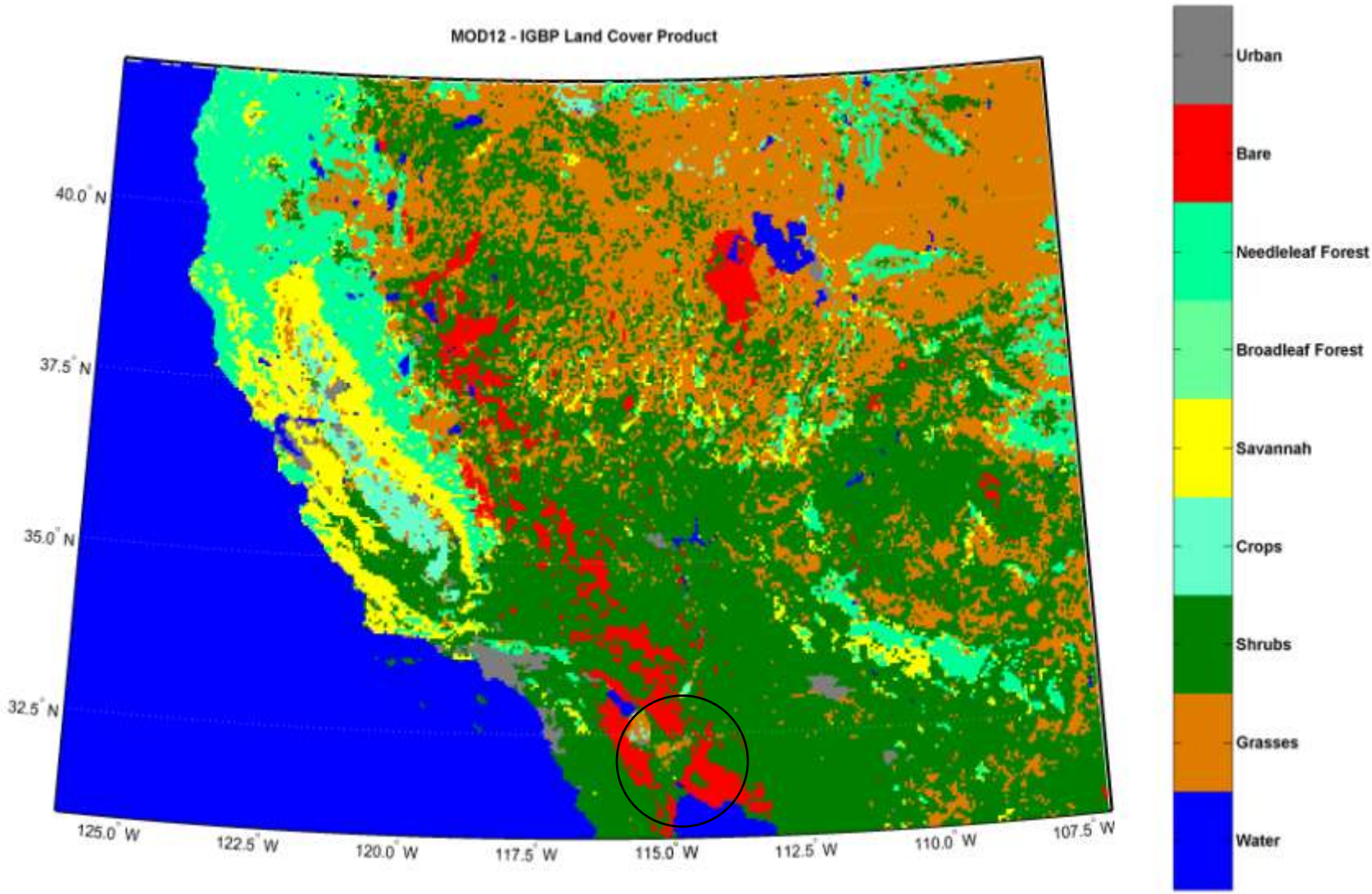
Algodones Dunes – MODIS v4 and v5 Differences



MODIS (v5) and MODIS (v4) Emissivity Difference at 8.3 µm



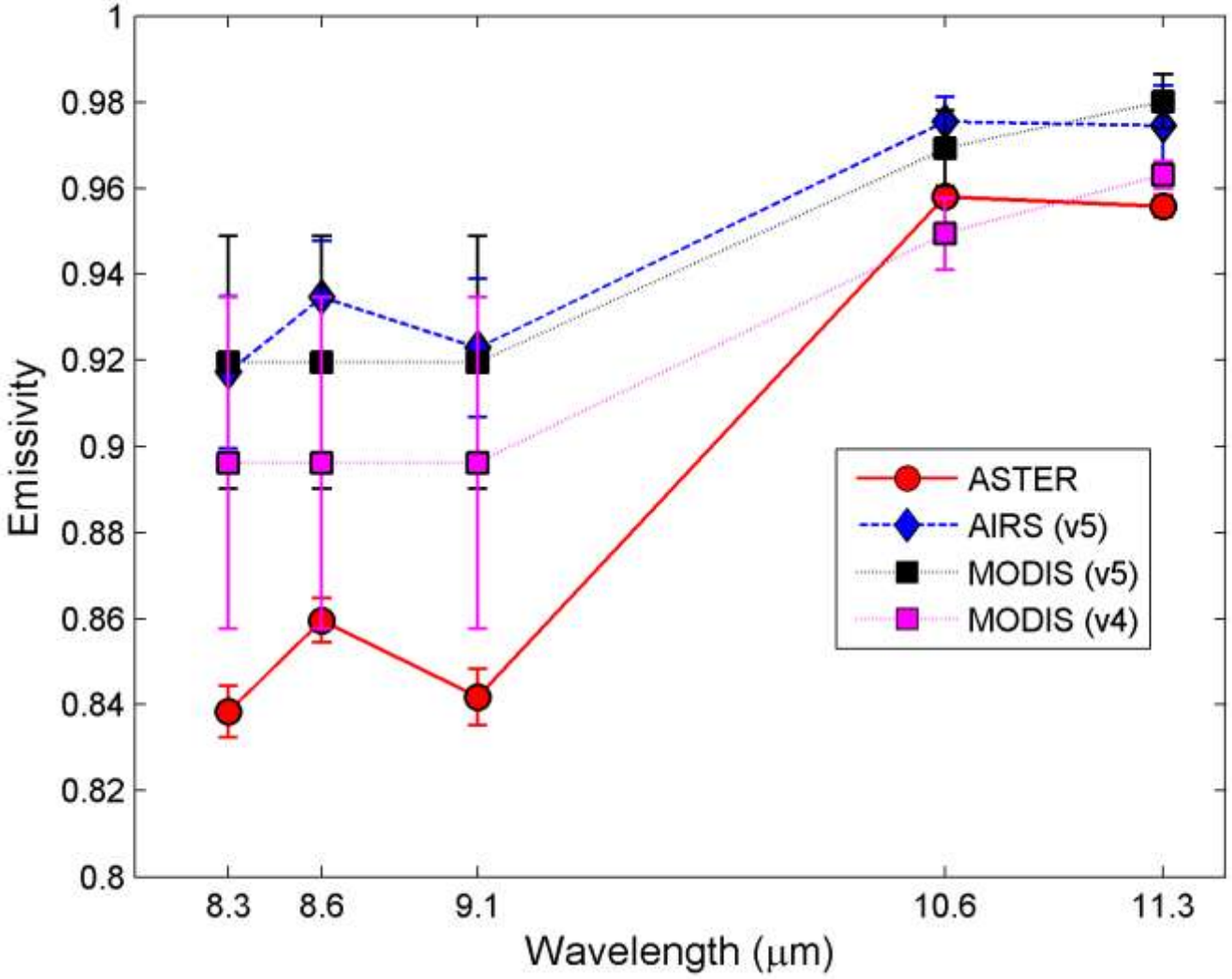
MODIS IGBP Land Cover Product



Low-Emissivity (Quartz)

All pixels with ASTER ε at 8.3 μm <0.85

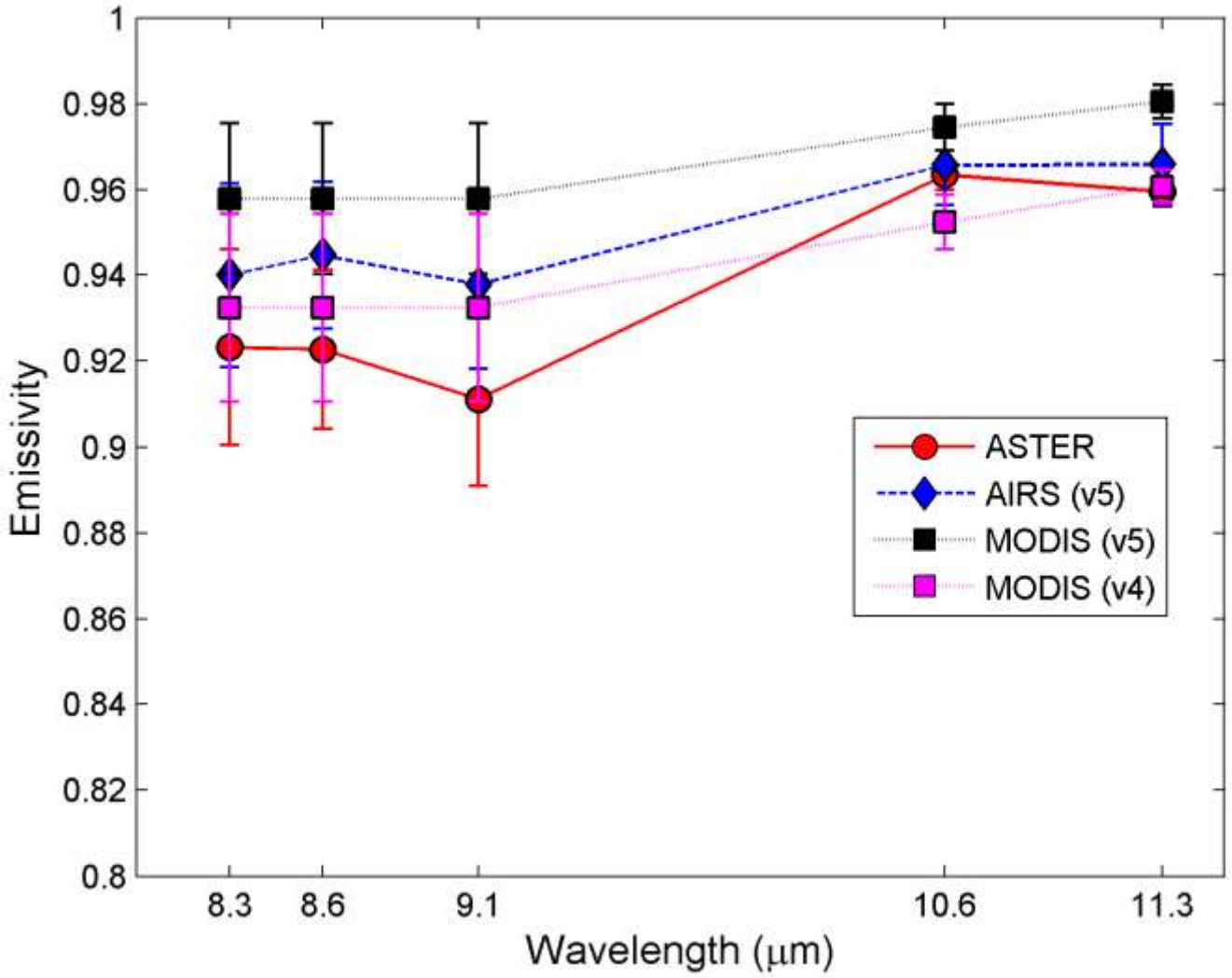
10 pixels



Mid-Emissivity (Mixed)

All pixels with 0.85 < ASTER ε at 8.3 μm < 0.95

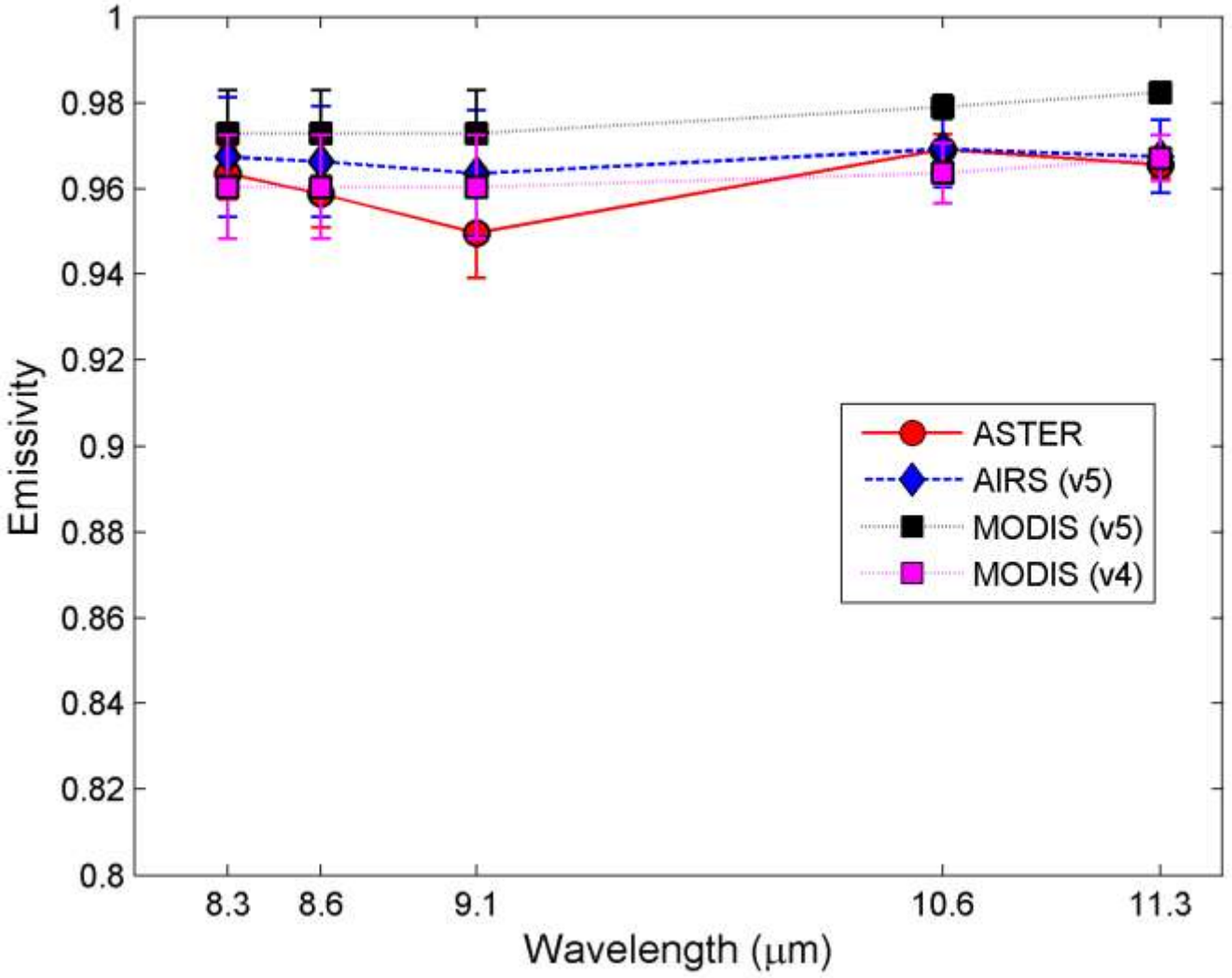
240 pixels



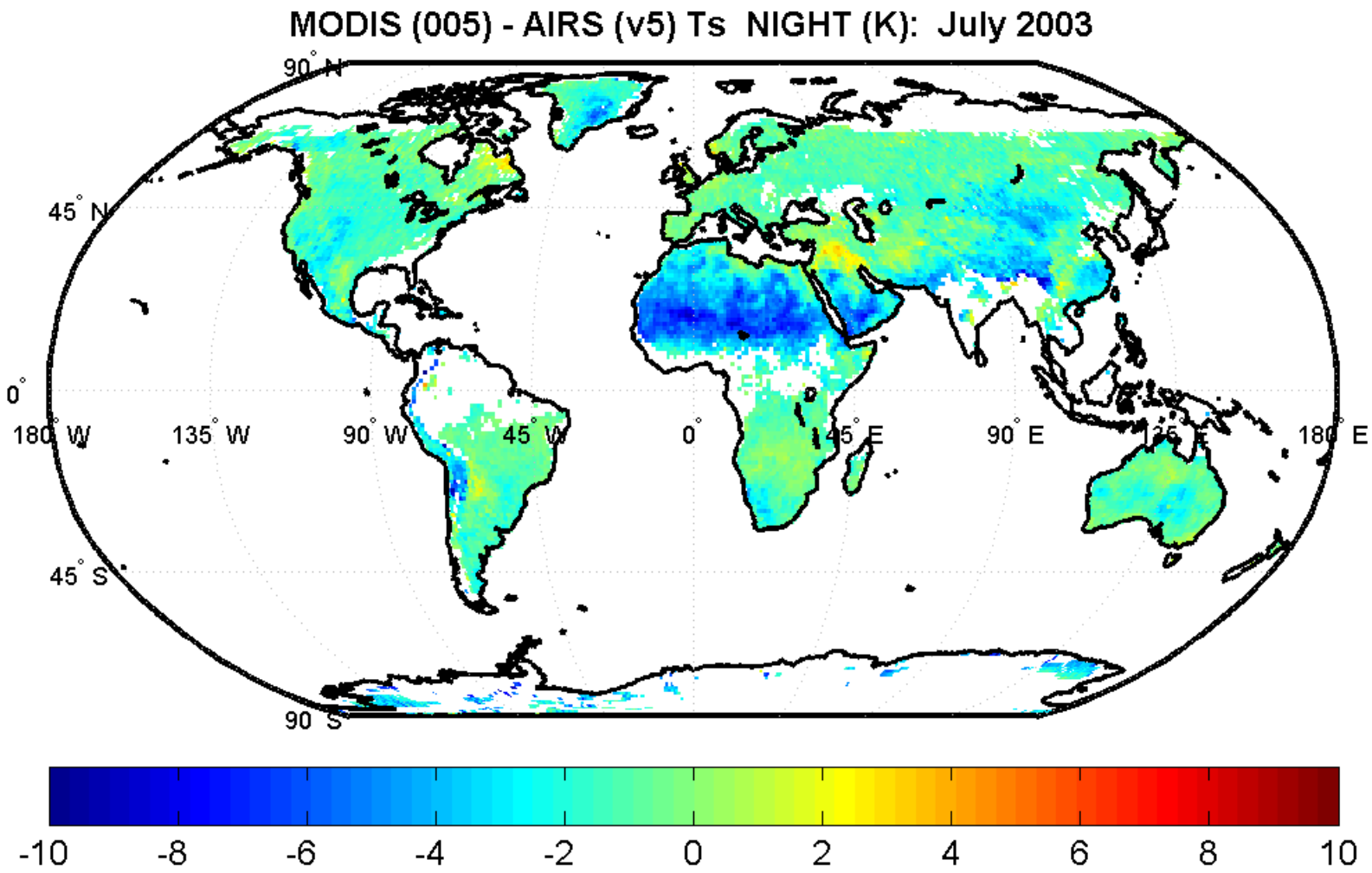
High-Emissivity (Vegetation/Water)

All pixels with ASTER ε at 8.3 μm > 0.95

259 pixels



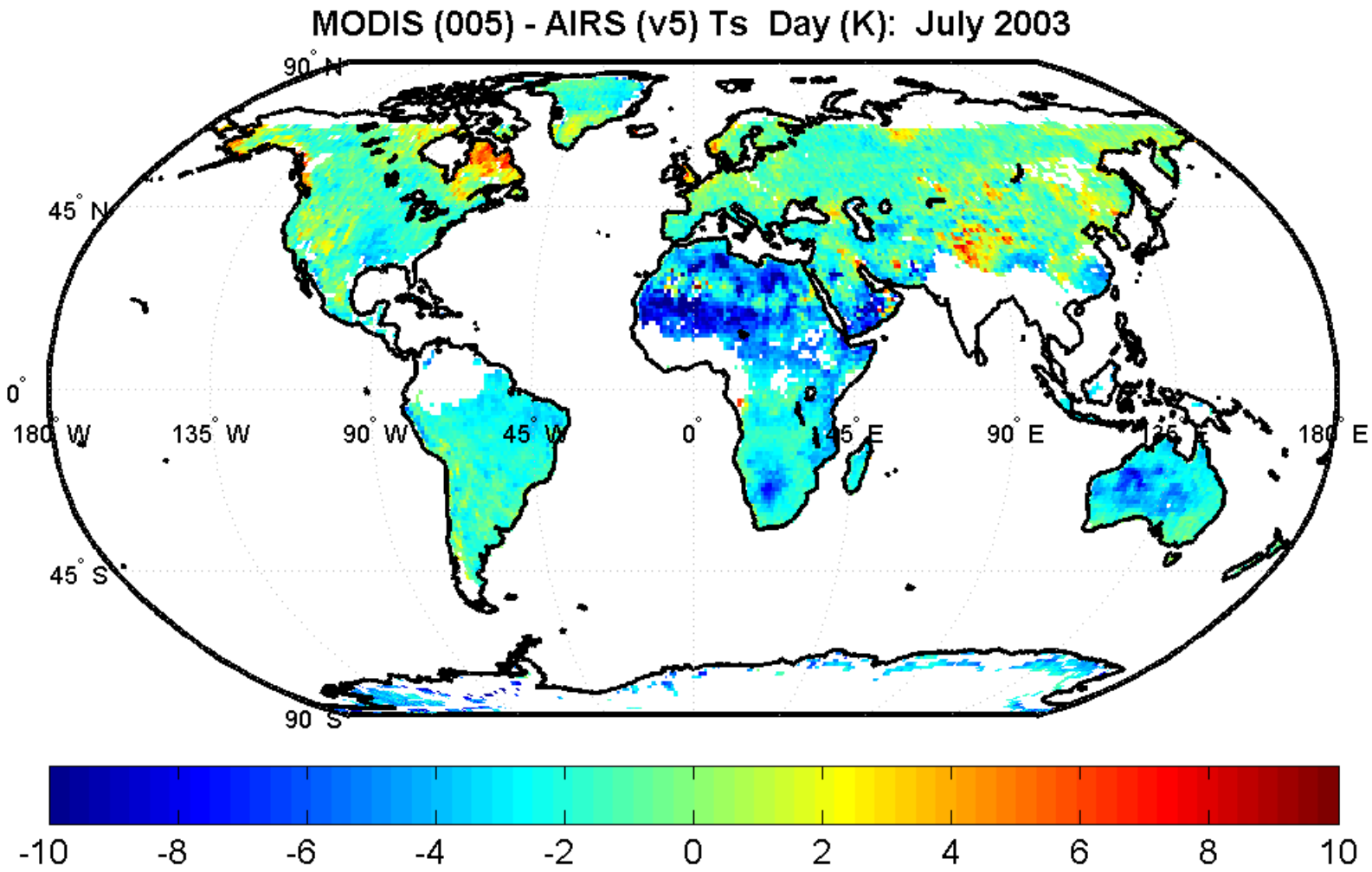
MODIS – AIRS NIGHT



Barren land shows MODIS cold bias (collection 005) up to 8 degrees.

* Knuteson

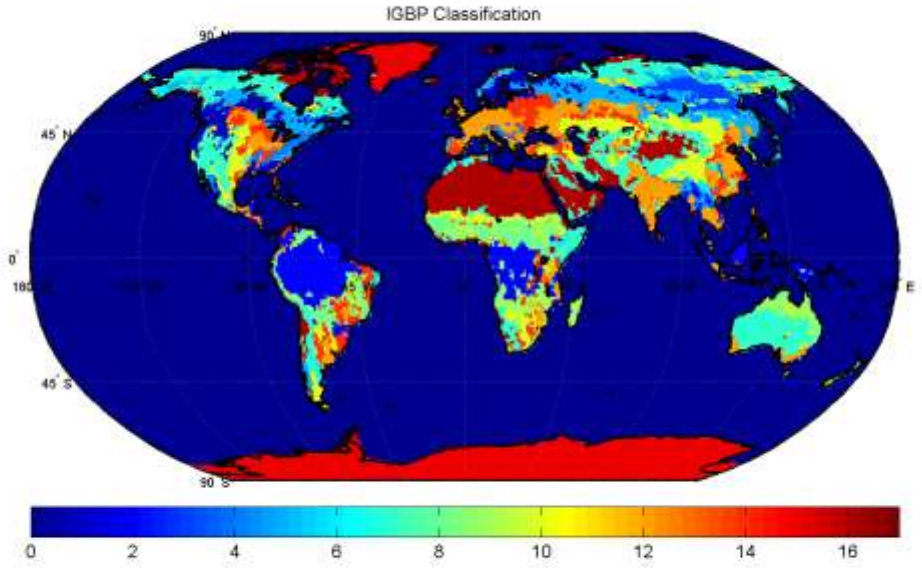
MODIS – AIRS DAY



Barren land shows MODIS cold bias (collection 005) up to 10 degrees.

* Knuteson

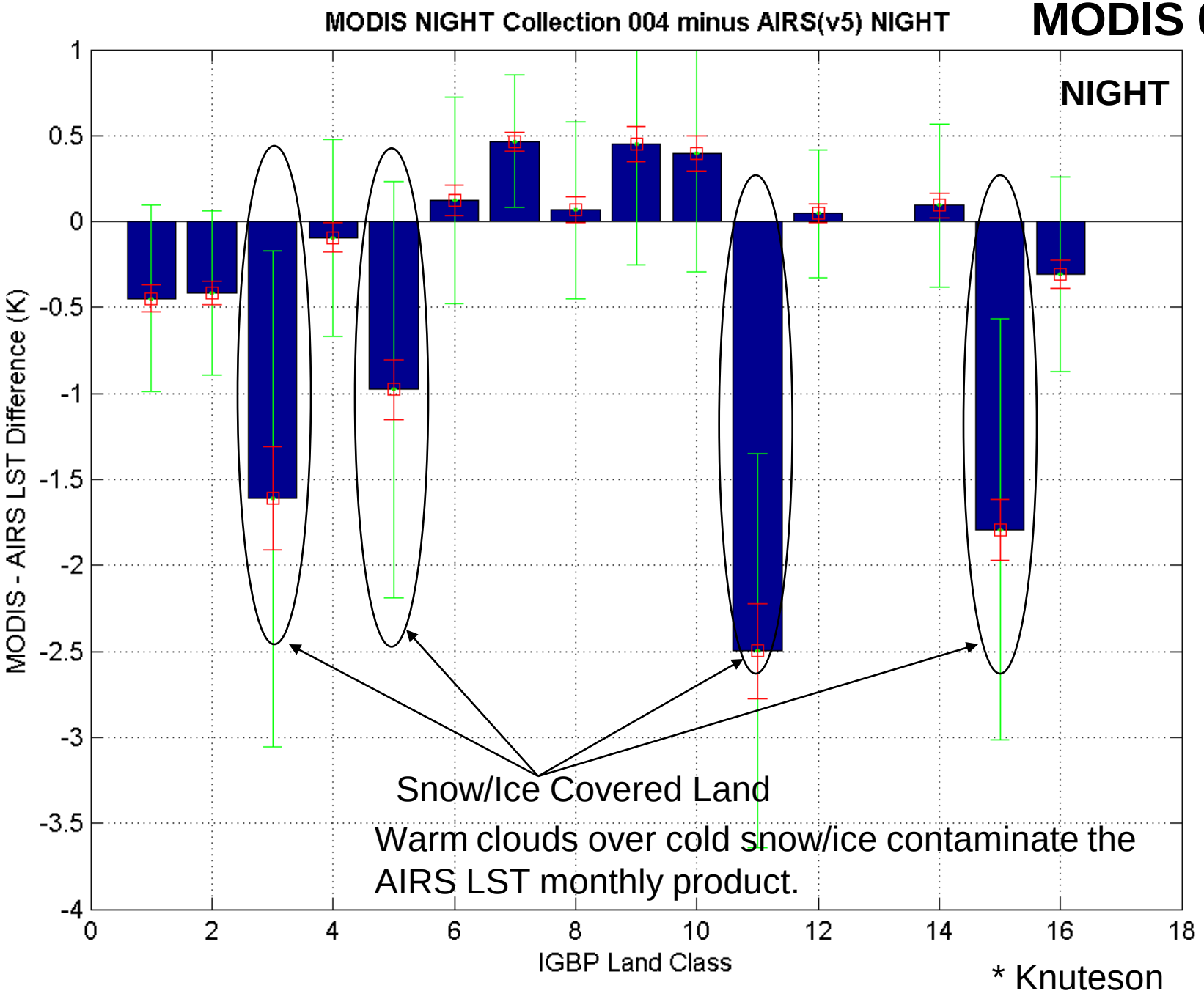
Use Land Classes (IGBP) to group the global data by land type for statistical analysis.



IGBP CLASS ID	IGBP CLASS Description
0	Water Bodies
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland/Natural Vegetation Mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Missing Data

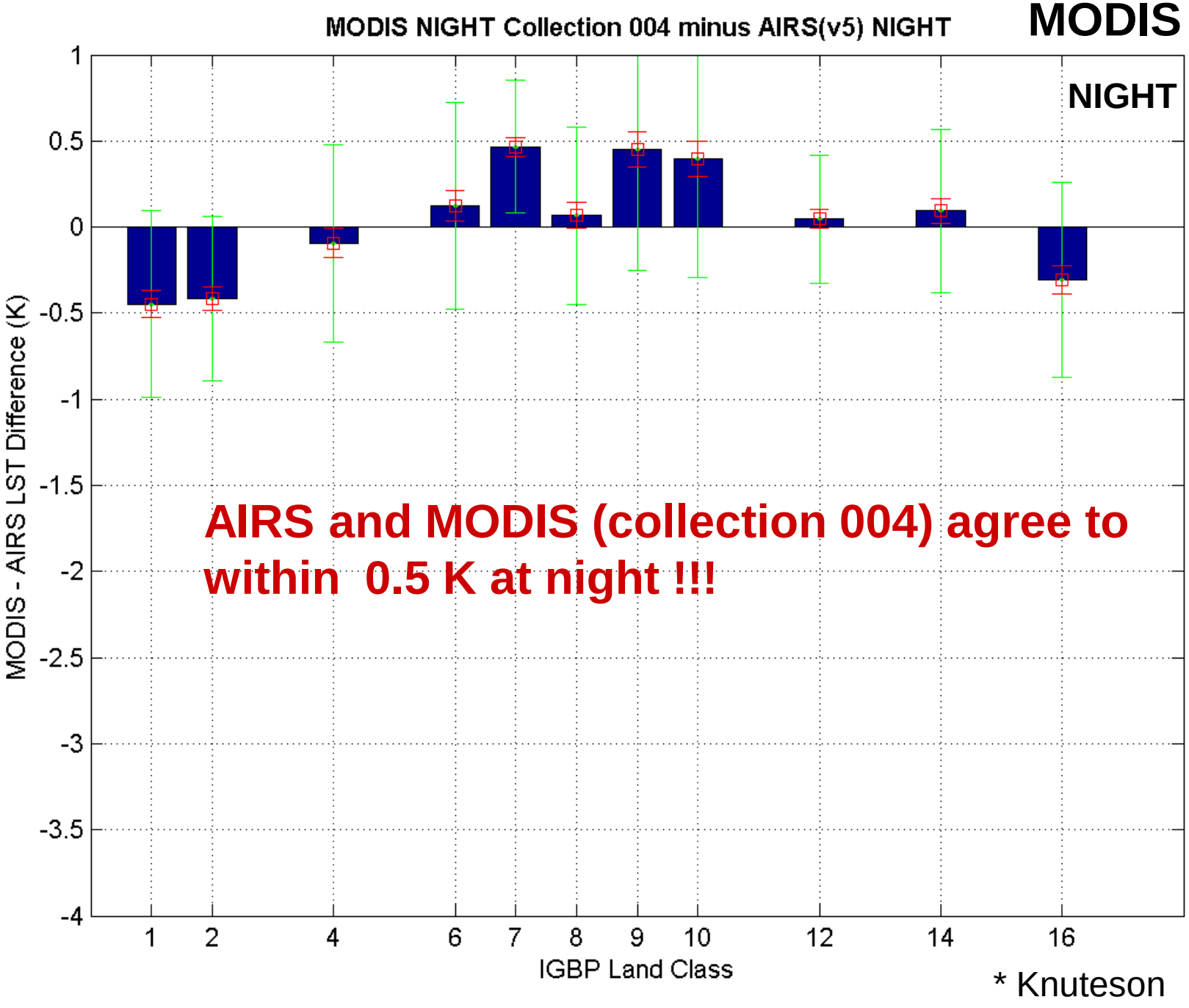
* Knuteson

MODIS 004



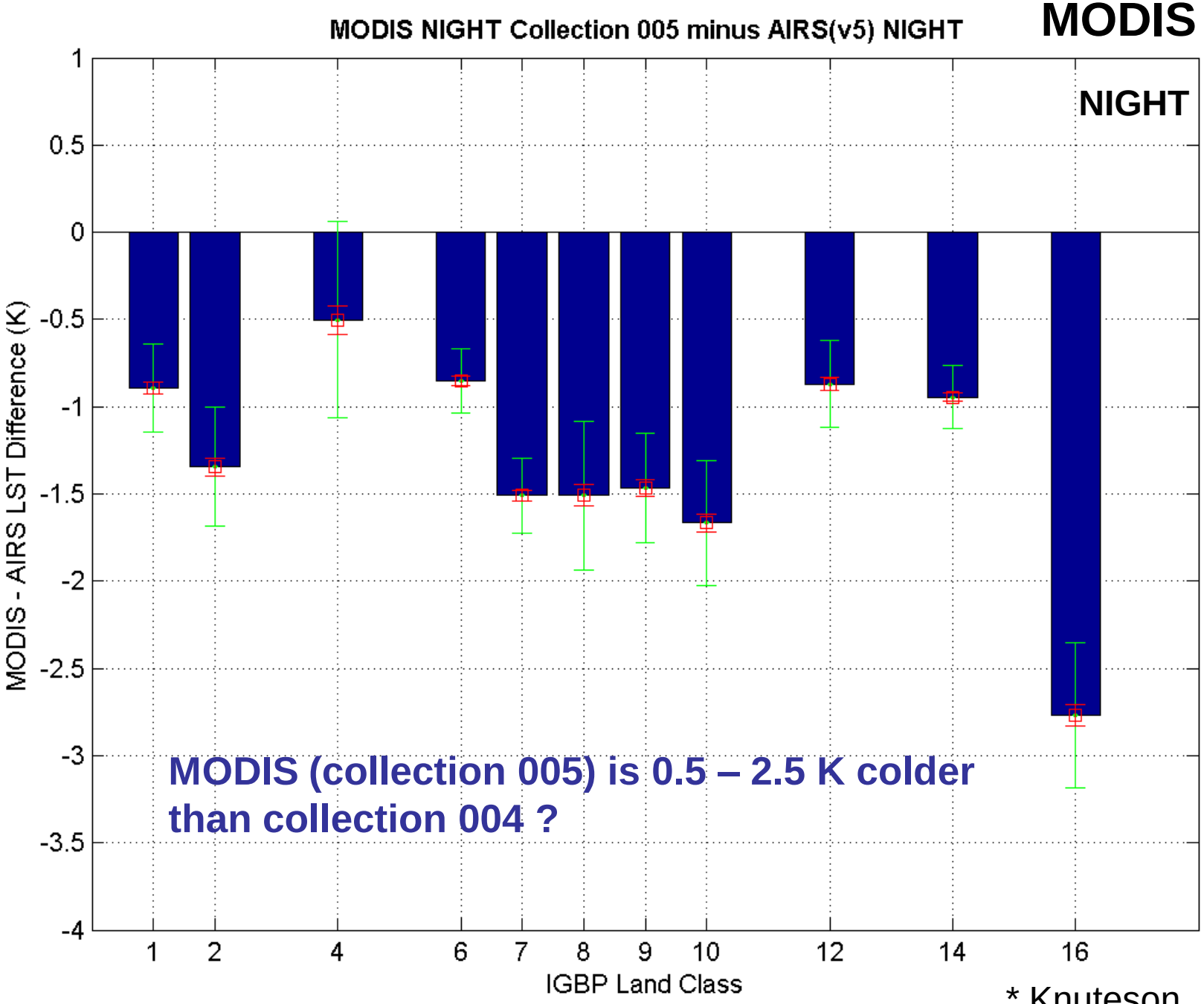
* Knuteson

MODIS 004



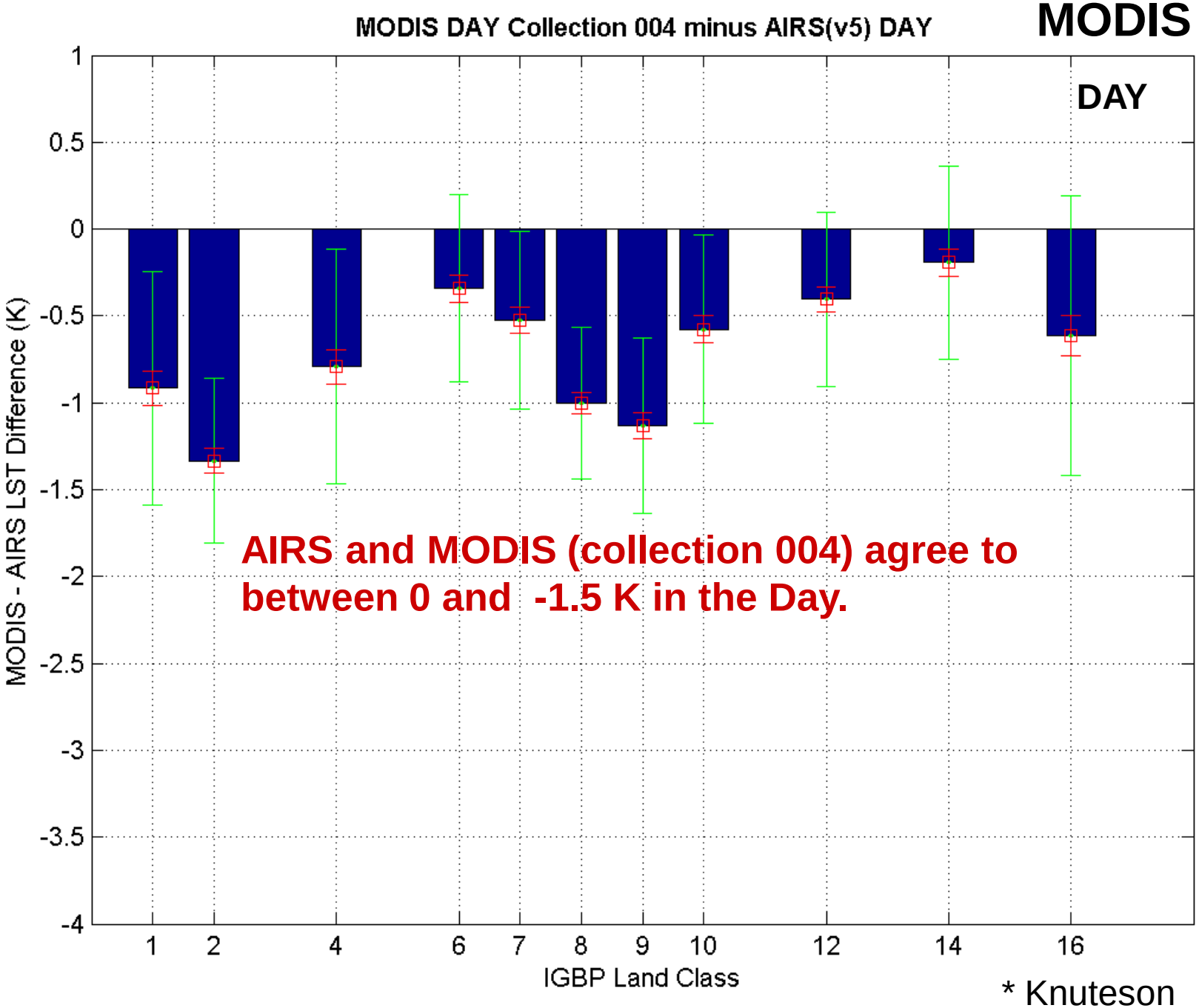
* Knuteson

MODIS 005



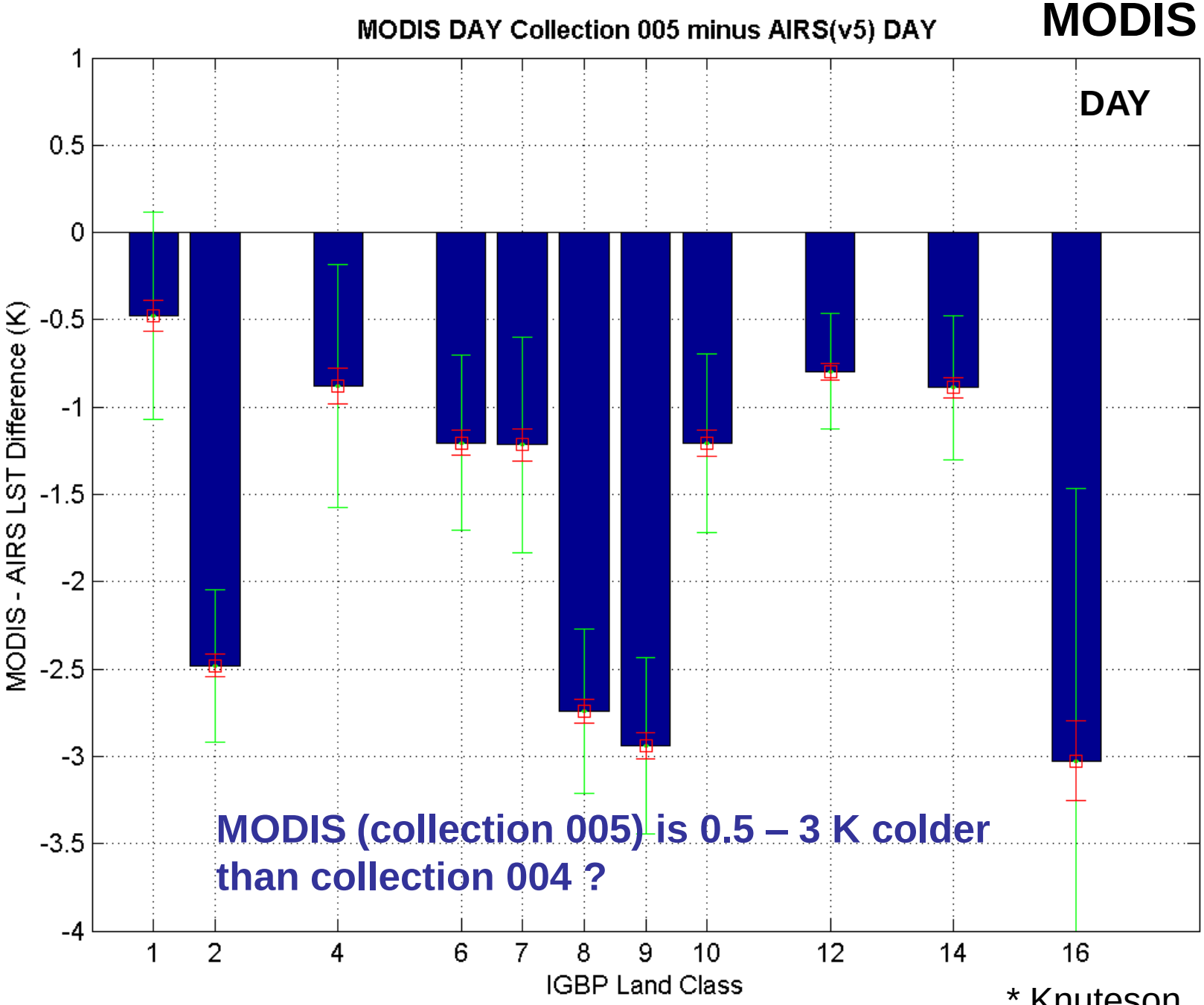
* Knuteson

MODIS 004



* Knuteson

MODIS 005



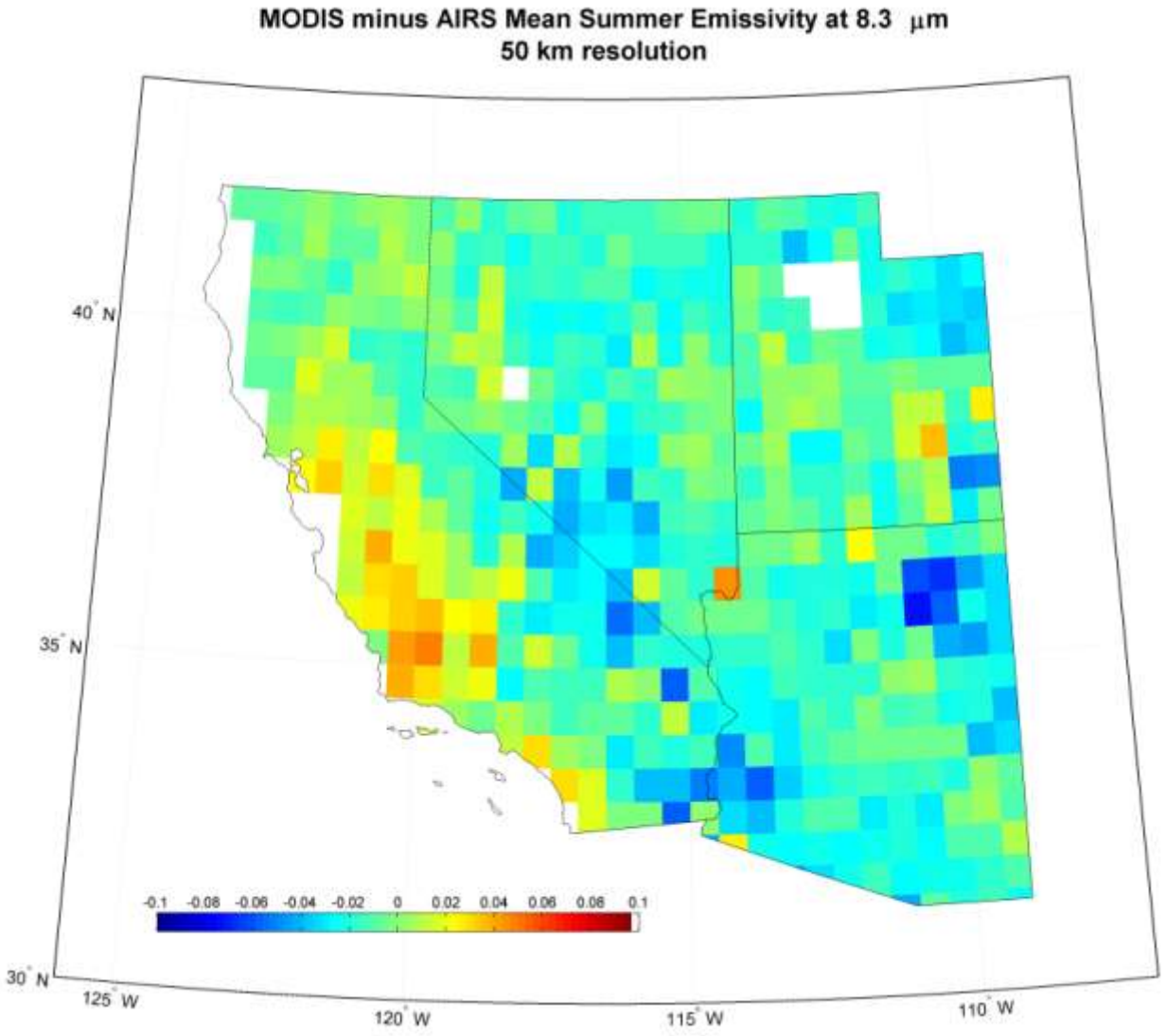
* Knuteson

Summary and Future Work

- ASTER validation results
  - <0.5 % rocks/sand, 1-3% over vegetation/water
- AIRS (v5) and ASTER emissivity differences
  - <1.5% over vegetated and mixed areas
  - Up to 7% over desert areas.
- MODIS (v4) and ASTER emissivity differences
  - 80% < 2%
  - Low < 6%
- MODIS v5 and ASTER emissivity differences
  - 50% < 2%
  - Low < 10%
- MODIS v4 and AIRS
  - < 0.5K
- MODIS v5 and AIRS
  - 0.5-3K

EXTRAS

MODIS (MYD11C3 V5) minus AIRS Mean Summer Emissivity Comparisons



LST&E Intercomparison Goals

- **International Workshop on the Retrieval and Use of Land Surface Temperature: Bridging the Gaps – Asheville, NC, 7-9 April `08**

- What are the natural spatial and temporal scales of the natural variability of the relevant quantities (LST&E)?

- To what degree can we identify BIASES in the LST&E products?

- When product algorithm changes are made (i.e. version changes), do we have a way of deciding if the intended improvements actually improve or degrade the product accuracy?

- More research and validation on low emissivities over barren areas

- Set of core validation LST&E sites over homogenous areas - set standard to which remote sensing LST&E measurements compared

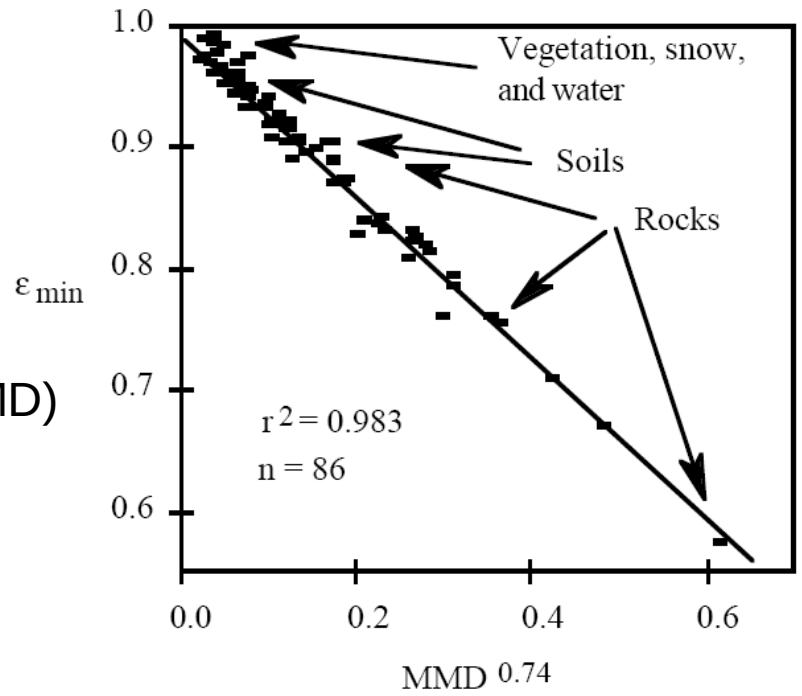
- **A possible Unified LST&E product for Earth Science Research?**

ASTER Temperature Emissivity Separation (TES) Algorithm

- Inversion of T and ε are underdetermined
- In TES, additional constraint arises from minimum emissivity vs spectral contrast
- Observed maximum-minimum difference (MMD) used to obtain unknown emissivity value
- Three error sources:
  - Reliance on empirical function
  - Atmospheric corrections (~1 K)
  - Radiometric calibration errors (small)
- Reported accuracy:
  - T within 1.5 K and ε within 0.015 (1.5%)

• **Strength:** low emissivity, high spectral contrast

• **Weakness:** high emissivity, low spectral contrast



$\varepsilon_{min} = 0.994 - 0.687 * MMD^{0.74}$

ASTER TIR Bands

Band 10	8.125 – 8.475 µm
Band 11	8.475 – 8.825 µm
Band 12	8.925 – 9.275 µm
Band 13	10.25 – 10.95 µm
Band 14	10.95 – 11.65 µm

Low-Emissivity (Quartz)

All pixels with ASTER emissivity at 8.3 μm <0.85

Wavelength	8.3 μm	8.6 μm	9.1 μm	10.6 μm	11.3 μm
Mean Bias					
ASTER – AIRS (50 km)	-0.071	-0.067	-0.071	-0.015	-0.021
ASTER – MODIS (5 km)	-0.079	-0.056	-0.076	-0.009	-0.024
MODIS – AIRS (50 km)	0.005	-0.011	0.001	-0.007	0.003
Std Dev					
ASTER – AIRS (50 km)	0.028	0.028	0.033	0.009	0.012
ASTER – MODIS (5 km)	0.016	0.015	0.016	0.008	0.005
MODIS – AIRS (50 km)	0.022	0.024	0.023	0.011	0.016

Mid-Emissivity (Mixed)

All pixels with 0.85 < ASTER emissivity at 8.3 μm < 0.95

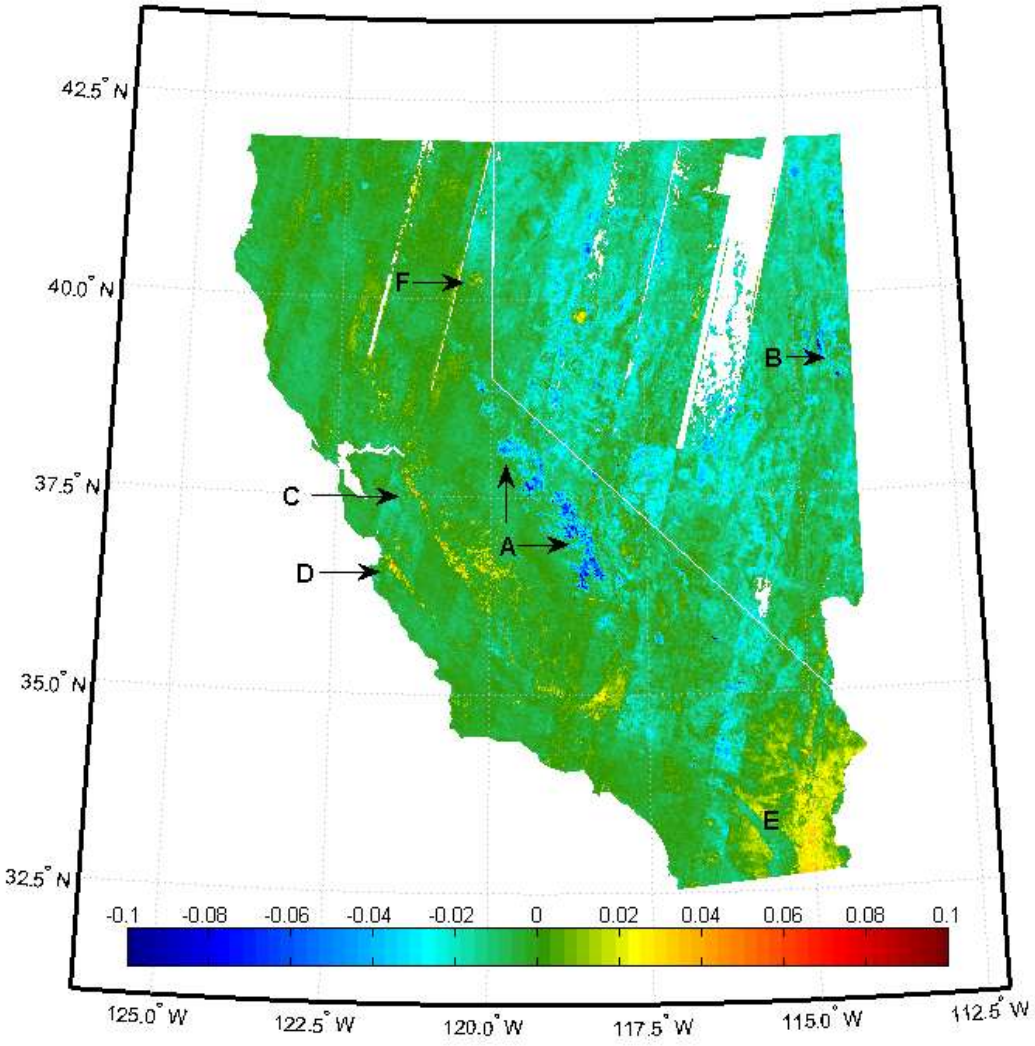
Wavelength	8.3 μm	8.6 μm	9.1 μm	10.6 μm	11.3 μm
Mean Bias					
ASTER – AIRS (50 km)	-0.017	-0.023	-0.027	-0.002	-0.006
ASTER – MODIS (5 km)	-0.038	-0.038	-0.050	-0.011	-0.021
MODIS – AIRS (50 km)	0.018	0.013	0.022	0.009	0.015
Std Dev					
ASTER – AIRS (50 km)	0.022	0.019	0.020	0.009	0.011
ASTER – MODIS (5 km)	0.018	0.015	0.016	0.005	0.005
MODIS – AIRS (50 km)	0.018	0.017	0.018	0.010	0.010

High-Emissivity (Vegetation/Crops)

All pixels with ASTER emissivity at 8.3 μm > 0.95

Wavelength	8.3 μm	8.6 μm	9.1 μm	10.6 μm	11.3 μm
Mean Bias					
ASTER – AIRS (50 km)	-0.003	-0.008	-0.014	-0.001	-0.002
ASTER – MODIS (5 km)	-0.008	-0.013	-0.022	-0.010	-0.017
MODIS – AIRS (50 km)	0.006	0.007	0.010	0.010	0.015
Std Dev					
ASTER – AIRS (50 km)	0.012	0.011	0.012	0.008	0.009
ASTER – MODIS (5 km)	0.010	0.010	0.012	0.004	0.004
MODIS – AIRS (50 km)	0.017	0.016	0.018	0.009	0.009

ASTER Summer minus Winter mean emissivity



ASTER L3 Emissivity Validation

- High spatial resolution (100m) makes validation possible
- Homogenous areas with known composition needed
- Samples measured in lab using FTIR
- Reflectance converted to emissivity and convolved to ASTER bands
- Geologic Samples
  - Quartz-rich Algodones dunes, southeastern CA
  - Carbonate-rich fan deposit, Cuprite NV
  - Stovepipe Wells dunes, Death Valley, CA
- 10 samples taken in 500x500m grid
- 2x2 ASTER pixels (1 pixel = 180 m)

Outline

- ASTER overview
- New ASTER L3 Emissivity Product
- ASTER Emissivity Validation results
- AIRS and ASTER Emissivity Comparisons
- MODIS and ASTER Emissivity Comparisons
- AIRS and MODIS Global LST Comparisons
- AIRS and MODIS Global Emissivity Comparisons
- Summary and Future Work

➢ MODBF – Seemann Baseline Fit LSE Database

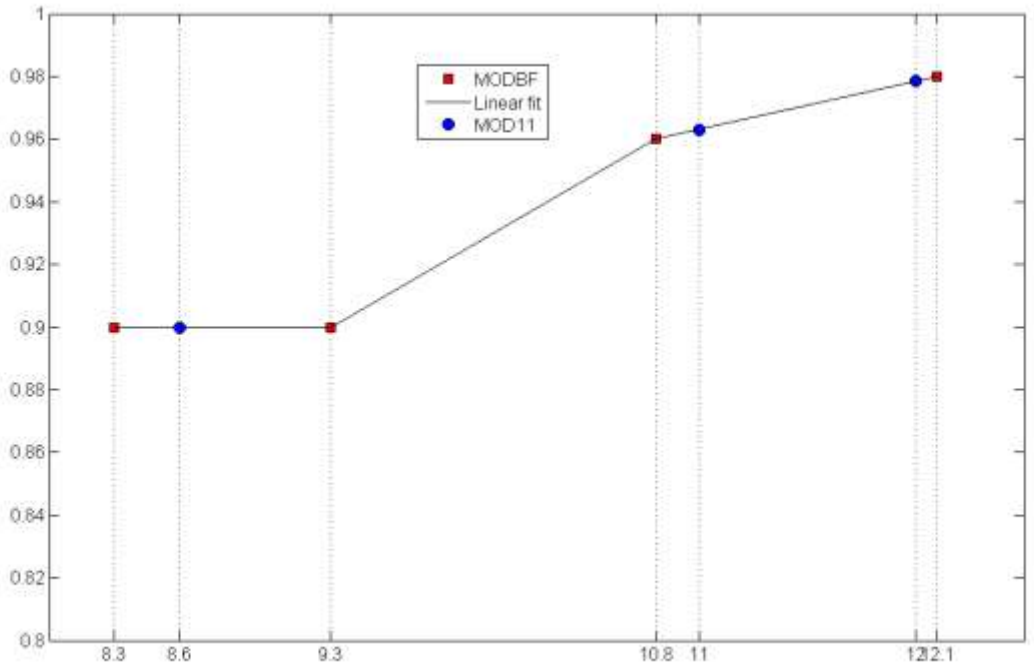
- Characterized by model with inflection points at 8.3, 9.3, 10.8 and 12.1 µm in TIR

➢ MOD11 – MODIS LSE Product

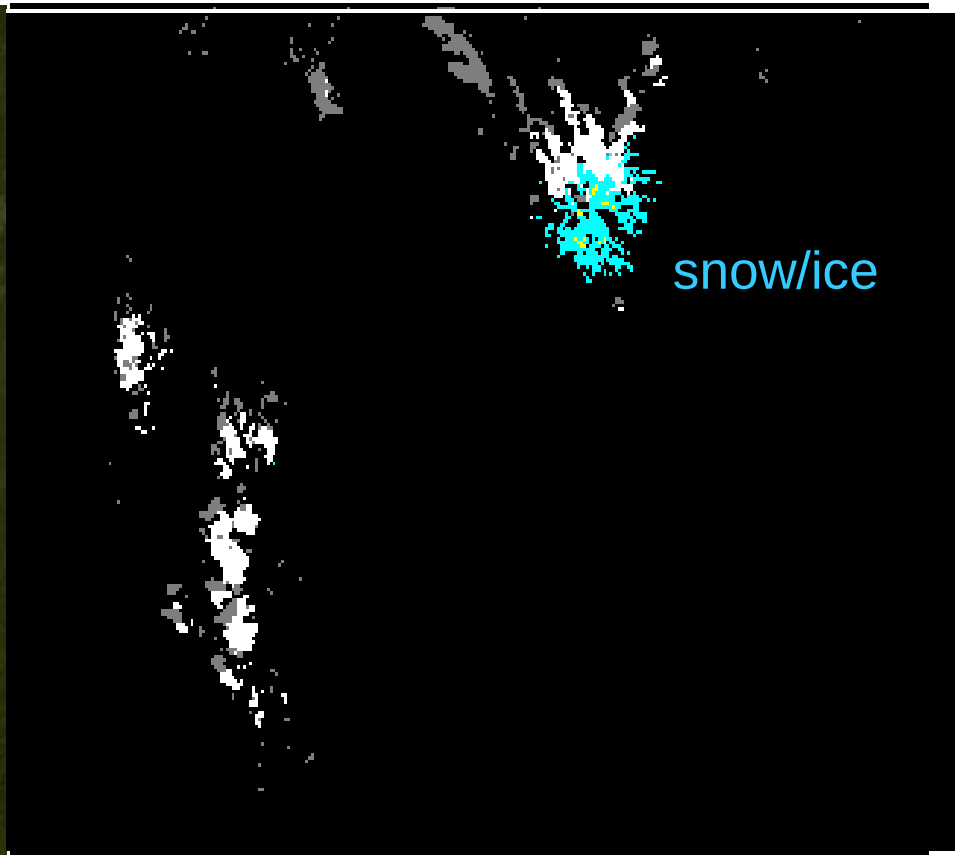
- Day-night emissivity retrieval with values at 8.6, 11 and 12 µm in TIR

➢ MOD11 values at 8.6 um are assigned to inflection points at 8.3 and 9.3 µm , while MOD11 emissivity values at 11 and 12 µm are used to extend line from hinge points 10.8 and 12.1 µm.

➢ MODBF can be linearly interpolated between inflection points for comparisons with other instruments, eg. ASTER



New ASTER Cloud Mask Algorithm (NACMA)



Cloud Shadow Clear

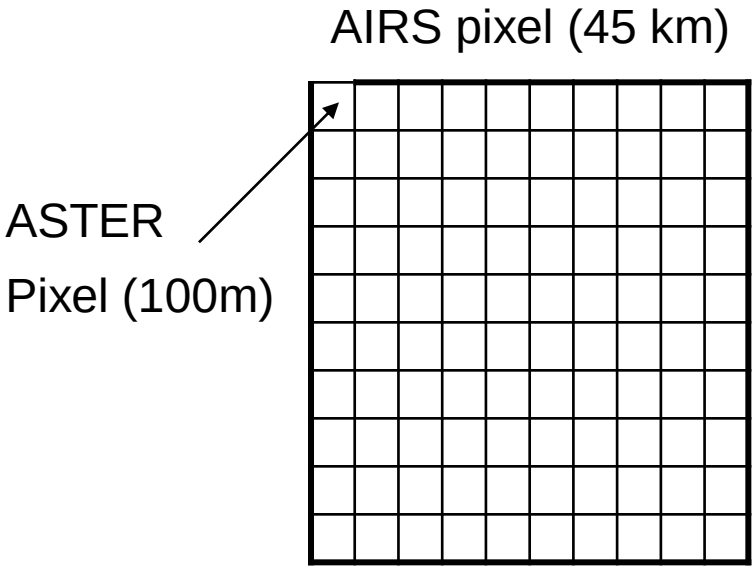
Sampling data with different spatial resolutions

Current:

$$\bar{e} = \frac{1}{n}\sum_{k=1}^{n} e_k$$

Proposed:

$$\bar{e} = \left[\frac{\frac{1}{n}\sum_{k=1}^{n} e_k B(T_k)}{B(T^*_{AIRS})} \right]$$



** But ASTER product is mean, seasonal T and e

Work in progress…..